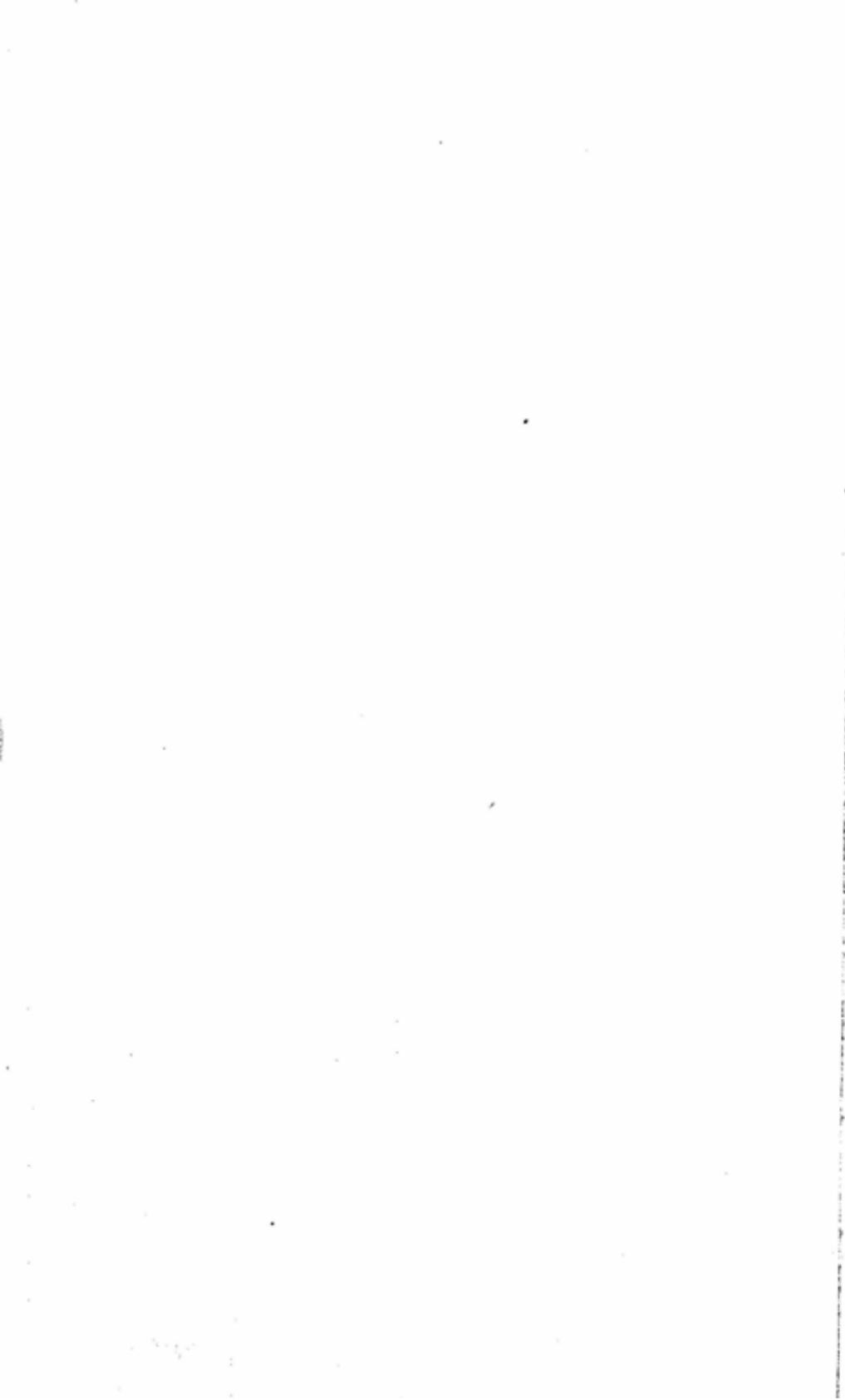


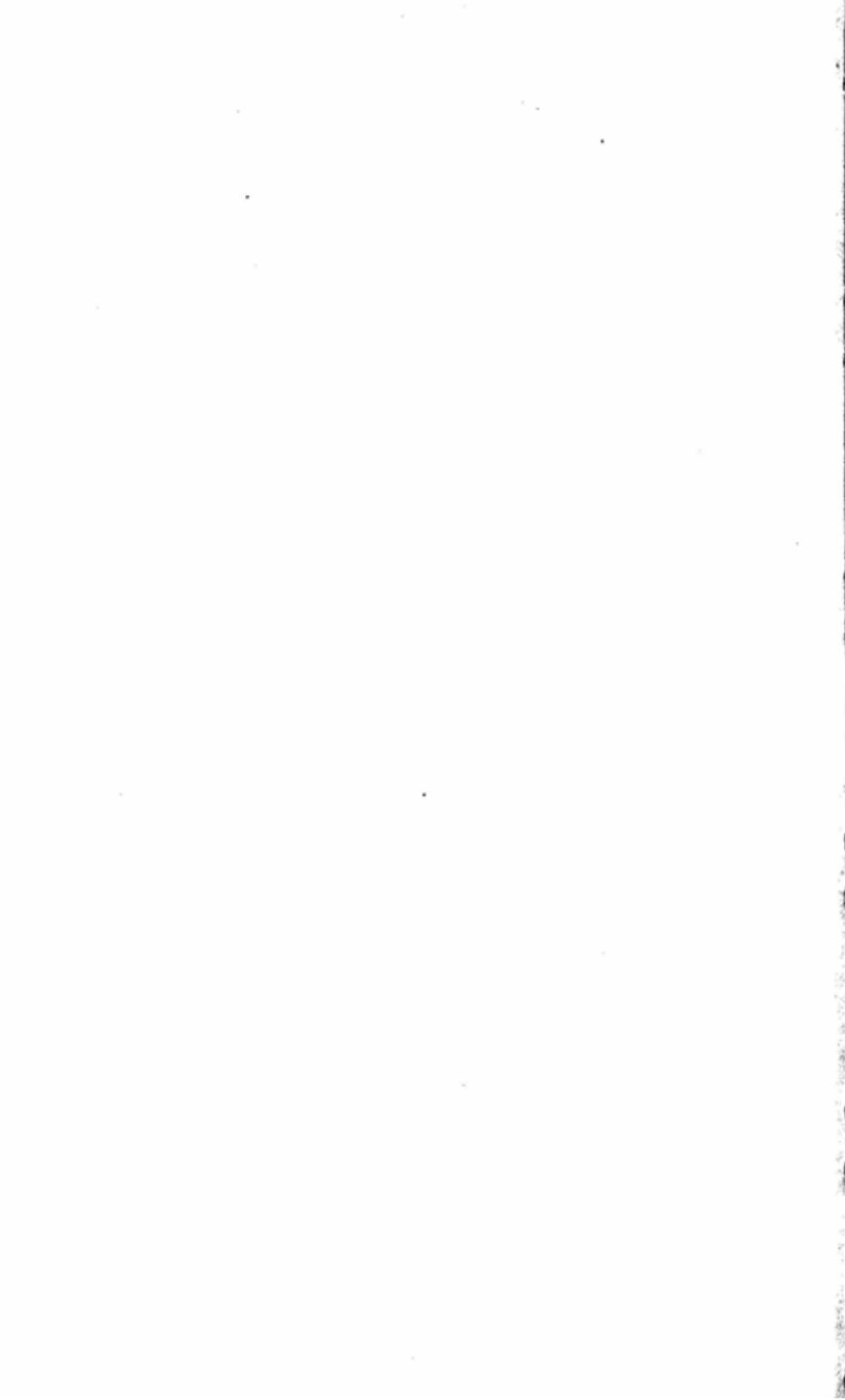
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Deep-Water Archaeology



Deep-Water Archaeology



by

FREDERIC DUMAS

translated from the French by

HONOR FROST

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Preface

ARCHAEOLOGISTS and amateur divers alike are at a disadvantage when excavating ancient wrecks in Mediterranean waters, since they cannot have acquired a wide comparative experience of this kind of site. Land methods developed for the excavation of ruined buildings are often irrelevant or inapplicable underwater. Wrecks were once mobile functional units, like motor-cars; if the excavator wants to do more than to collect such artifacts as are easy to salvage, he must understand the laws of submarine gravity and geology which preserved the parts of a ship, and held them in a significant relationship. Furthermore, if a functional unit is to be reconstructed, there can be no question of partial excavation.

In practice the archaeologist will have to move several hundred tons of sand and cargo, underwater, in a controlled manner that will permit of recording. Other scientists: geologists, biologists and ichtheologists can do useful research in the sea without much diving experience, because their work depends on observation and the taking of samples. Archaeologists, on the other hand, must tackle heavy manual labour, control powerful machines and at the same time possess a degree of seamanship. Since excavation entails destruction, they cannot repeat their experiments; antiquities may be unique and even if they are not, the number of wrecks is limited.

Many misleading accounts of 'submarine excavations' have appeared in the press but the fact remains that, as yet, no antique wreck has been examined and recorded in its entirety. In these

PREFACE

circumstances it seems to me useful to set down some of the technical aspects of wreck excavation, in Mediterranean waters, as they appear to me after twenty years experience as a diver.

FREDERIC DUMAS

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Drawings by Honor Frost

Introduction

By Professor W. F. Grimes, C.B.E., M.A., F.S.A., F.M.A.
*Director, Institute of Archaeology,
University of London*

THESE is that about the term 'underwater archaeology' or its variants to strike uneasiness in the mind of the archaeologist who practises on the more normal element. He cannot but be aware of treasure that has come by chance from the sea in the past; and in more recent years rumours of expensively mounted expeditions with a frankly treasure-seeking purpose will have reached him.

Yet there can be no doubt of the value that underwater work holds for archaeology in more than one aspect. There is not only the 'treasure', the actual objects which even when divorced from their context excite and interest on their own account. There are the potentialities for a wider knowledge of complete cargoes, with its bearing upon cultures, communications and economics. There is the possibility of new and otherwise unobtainable information about ships and ship-construction. There is the opportunity, apart from the exploration of wrecks, to learn about the now submerged structures of harbours and the like which present another aspect of man's relationship with the sea; and even about the environmental changes demonstrated by such evidence as the ancient submerged shore-lines which have had an important bearing on man's life in the past.

All this is treasure in the true sense and like everything else that is worth having it has to be worked for. Knowledge is not won without technique, whether on land or beneath the sea. This technique M. Dumas' book does pioneer work to provide:

INTRODUCTION

any who wish to develop the subject must study it or something like it and will do so in the knowledge that it is based upon sound experience. As one whose peace of mind in the sea is in inverse proportion to the nearness of my feet to the floor of it I am uniquely unqualified to comment on diving methods as such; but I commend this book to all who wish to combine the physical activity with a worthwhile scientific objective.

W. F. GRIMES

I

Preliminary Classification of Sites

SUBMARINE archaeology may be defined as the study of ancient wrecks, ports, submerged towns and other offshore sites marked by scattered pottery and anchors. We are not yet aware of the full significance of the latter and there may be further evidence which we have not recognized or discovered.

The examination of harbours, while contributing to a better understanding of the past, is an extension of land archaeology. Submerged towns capture public imagination, though when the difficulties of excavating buildings under water are compared with similar work on shore the undertaking is hard to justify, especially when there are so many land sites waiting to be dug. The importance of ancient wrecks is evident but their excavation is bound to be long and costly. Until recently no attempt has been made to develop scientific underwater excavation technique with the exception of the work started on the Roman wreck at Spargi,¹ in Italy, and on the *palafittes* in Swiss lakes.² Underwater 'archaeology' has amounted to lifting objects and even this salvage has been left unfinished.

Methodical excavation was carried to completion for the first time in Turkey in 1960 on a Bronze Age wreck at Gelidonou

¹ 'Note tecniche sul rilevamento e lo scavo della Nave Romana di Spargi', Gianni Roghi. *Bollettino e Atti*, 1958-9. Centro Italiano Ricercatori Subacquei.

² *Informations Sous-Marines*, No. 6, 1958, pp. 18-24, W. Haag.

CRIS, Revista de la Mar 2, No. 23, 1960, pp. 27-8, W. Haag.

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Burnu,¹ by a team which included an archaeologist, draftsmen, and photographers, all working on the bottom. It is regrettable that the site in question was utterly atypical. The bottom was rock covered by a sprinkling of sand. The cargo itself was unrecognizable, the objects being welded together inside lumps of concretion. In these circumstances, it was impossible to develop a technique applicable to the normal run of wrecks and regrettably, the expedition did not include a geologist or a biologist specializing in submarine research.

Where Wrecks are Found

Statistical analysis of the numerous wrecks known up till now, would be misleading, as they have all been discovered on fertile parts of the sea-bed.

Wrecks have been found by commercial or sporting divers in areas visited either for their potential returns, in the form of fish or sponges, or because they happened to be picturesque, that is to say, places near rocky, coastal slopes or shoals. Admittedly, these are likely spots, but experience shows that, for less obvious reasons, antique wrecks also lie some distance from the shore.

In the South of France, fishermen draw up amphorae on certain known lines of trawl. Similarly, while we were working on the Bronze Age wreck in Turkey, men who dragged for sponges with a special trawl called a *congoa*, often brought us Greek, Roman or Byzantine amphorae and on one occasion, pottery lamps. Bottoms suitable for trawling are flat and of no interest to pleasure divers, yet it seems that many wrecks lie there and these would probably be among the most interesting, because the best preserved.

Trawling is practised where there is considerable marine life; however, areas where fish and sponges abound, are the exception

¹ *National Geographic Magazine*, Vol. 117, No. 5, May 1960, pp. 216-18.
Peter Throckmorton.

Antiquity, Vol. XXXIV, No. 135, Sept. 1960, pp. 216-18, Honor Frost.

Discovery, May 1960, pp. 194-6, Honor Frost.

Expedition, Bulletin of the University Museum of the University of Pennsylvania, 1961, Vol. 13, No. 2, pp. 2-11, George Bass.

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in Mediterranean coastal waters. There may well be ancient wrecks on deserts of sand or mud, which could only be found as a result of deliberate, methodical prospection.

Anchorages

At certain points along the Mediterranean coast the sea-bed is littered with ancient debris: broken pottery, anchors and other objects. At first glance one might suppose they came from a wreck, but the way in which the sherds are dispersed and their differing dates, indicate that we are looking at a place where the ancients dropped anchor, either in order to take shelter, or to transact business with the land. Their mooring was marked by certain accidents: things fell overboard or were jettisoned while the seamen took advantage of calm waters to tidy their load. Because the water is calm at such places, this jetsam is never completely covered by sand. Similarly, where modern cargo and, still more, passenger ships, drop anchor, the bottom is strewn with cans and crockery.

Then there is a second kind of site on isolated reefs or shoals, which is marked by groups of ancient anchors or their stocks. Such exposed places must not be confused with the above-mentioned, sheltered moorings. At first it seems debatable whether the anchors denote fishing-grounds or forced moorings, but it must be remembered that the merchant ships of antiquity could not, in all probability, sail against the wind. It follows that, an unfavourable wind would force them to stop and wait until it changed direction. Even in fine weather, in the Mediterranean, the wind can veer from east to west in the course of a day, in accordance with the sun. The cycle is neither regular nor inevitable, but it is true to say that winds change from day to day, if not in a single day.

It is often impossible to anchor by a steep coastline, because the water is too deep. Furthermore, a ship which was very near the coast might not be able to get away if a strong wind blew up, forcing it on to the shore. Sailors of antiquity were therefore faced with a choice: in the case of a strong wind they would have to turn about and find a sheltered mooring, while a tem-

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porary fluctuation would force them to anchor provisionally on any convenient reef or shoal, or even on the tip of a cape. Pottery remains are relatively scarce on these offshore sites, whereas in the sheltered moorings, especially those in the vicinity of towns, there may be deposits of sherds on the bottom, in several layers. Such sites are stratified (see p. 52).

Types of Sea-bed: Types of Wreck

The preservation of an ancient wreck will depend largely on the type of bottom on which it lies.

A flat coastline where the sand descends gently to depth is not promising. Scattered remains will be buried after the ship has been broken by storms and swell. Rocky shores are more likely to retain traces of shipwreck: parts of the ship or its cargo are preserved in declivities. Sherds can still be distinguished under the camouflage of concretions, but in shallow water the sea breaks everything and the dislocation of a wreck decreases its interest.

Even here we find exceptions: in some parts of the Mediterranean, where the bottom slopes very gradually to depth, there are places near the shore, under only a few metres of water, where the full force of the swell has been broken. Here wrecks will have been covered with sand and growths of Poseidon grass, before they could be broken up. In antiquity the mouths of even quite small rivers were used as ports; at the mouth of the Hérault, for instance, remains of wrecks are still visible on the bed of the river, about one kilometre upstream from the sea. On a coast where a gentle, sandy slope gives place to deep water, the wrecks will be of no great interest, since they will have been broken up and dispersed by storms, before being buried in sand.

Steep rocky coasts, typical of the northern Mediterranean, produce the best wrecks. Almost vertical cliffs continue under water to a depth of between 30 and 50 metres; then, after inclined rock-fall, a sandy bottom slopes gradually down towards open sea. A ship blown against precipitous rocks crashes until she springs a leak large enough to sink her. She then drops, without further damage, to the bottom of the cliff.

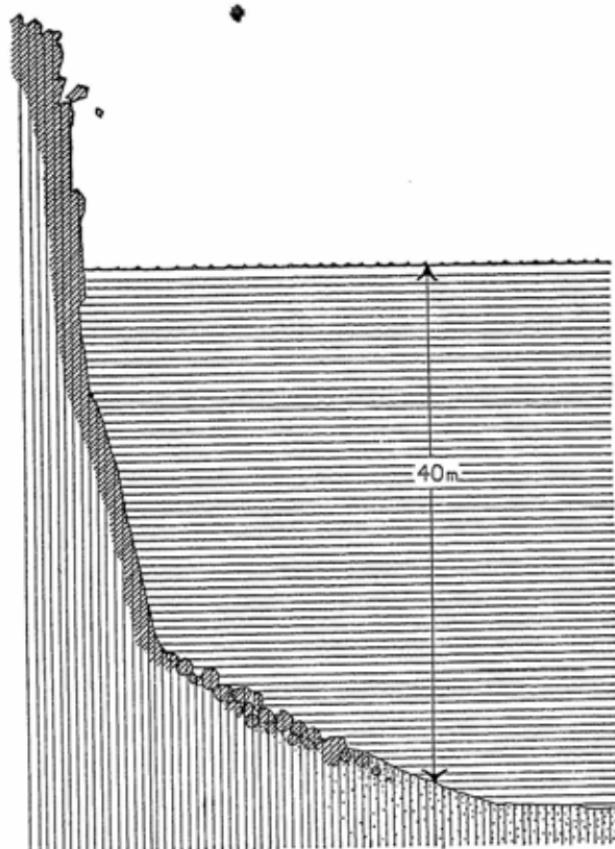


Fig. 1. One type of Mediterranean cliff with line of rock-fall giving on to sand. In these conditions, wrecks usually lie just beyond the rock-fall, are fairly deeply buried in sand.

Rains and rivers carry the products of land erosion into the sea, where they are sorted and redistributed. The sea also produces her own waste from the life she fosters: shells, bones, calcareous growth and the like. These processes affect the coastal strip accessible to divers. The heaviest erosion products come to rest near land while the tiniest, which eventually become mud, are carried farthest.

At the foot of rocks or cliffs that emerge above the waterline, ancient wrecks are covered with a layer of sand caused by ero-

PRELIMINARY CLASSIFICATION OF SITES

sion, which is proportionately deeper the nearer the wreck to the land. In such places the accumulation of matter which, in the course of centuries, has fallen from above hampers submarine excavation. Shells, sea-urchins and calcareous growths drop from the zone licked by waves. These are supplemented by rocks, which have been detached above the water-line. The Roman ship at the Grand Congloué,¹ off Marseilles, lay at the base of an almost vertical cliff which continues under water to a depth of 40 metres. Only the necks of the top layer of amphorae emerged, here and there, from the sand. Rocks of all sizes, some weighing several tons, had fallen on to the wreck.

At Anticythera,² the ship whose cargo now adorns the Athens Museum, lies at a depth of 50 metres, at the base of a vertical cliff. Most of the wreck is on sand and the remainder on rock-fall. Excavated by Greek standard apparatus divers at the beginning of the century, practically nothing remains to mark the spot. However, by gently moving a shallow layer of sand, I was able to see that the hull was still there in an excellent state of preservation and with it, doubtless, quantities of small objects. A few hundred metres away we found another wreck, with a cargo of amphorae, lying in similar conditions.

At Cap Drammont³ near St. Raphael, a submarine cliff (1 metre below the surface) runs out from a small island, itself the extension of the cape. At the cliff base, in a depth of 30 metres, lies the wreck which was examined in 1959. A layer of amphorae, leaning at an angle of 45°, soldered together and covered with a pie-crust of concretion, was visible above the sand.

¹ *National Geographic Magazine*, January 1954. J. Y. Cousteau.

Gallia Monograph (in publication), F. Benoît.

² *Ephemeris Archaeologiki*, Athens, 1902.

Archaeology (U.S.), Winter 1948, George Karo.

³ *Le Plongeur et l'Archéologue*, published 1960 by Confédération Mondiale des Activités Sub-Aquatiques, 34 R. du Colisée, Paris, pp. 23-5.

A. Siverine. Duplicated, Technical Report by Office Française de Recherche Sous-Marine for the Ministère de l'Education Nationale, C.N.R.S., 1959.

Typologie des Amphores et Construction Navale, Imprimerie Nationale, Paris, 1960. M. F. Benoît.

Beyond the direct influence of the coast, wrecks are not, on the whole, so deeply buried. Even so, they vary considerably between one place and another within the same region. In any wreck, its relief above the surface is a factor of bad preservation, but the vulnerability of exposed parts is frequently offset by a lessening of the greedy, destructive, marine life which devours offshore wrecks. All things considered, proximity to the coast can be regarded as a disadvantage.

The wreck at Albenga¹ is 1,500 metres from land and 40 metres deep, on a bare, flat expanse of mud. Despite the recovery of objects that has gone on, the tumulus of amphorae is still recognizable. About 2 metres high and even three in some places, it remains a well-defined mound in the shape of a ship.

The Mahdia² wreck was also at a depth of 40 metres and 6,000 metres off a low-lying coastline. The bottom there is hard and flat, with only a sprinkling of marine life. This ship was hardly buried. The hull itself is almost on the surface and the huge, lead anchor-stocks, only a few metres from the wreck, were entirely visible.

Wrecks in Weed

Fields of long Poseidon grass occur on many parts of the Mediterranean coast. These may start a few metres from the surface; the grass grows on sand but not mud, so they are not found below about 40 metres. The fields known as 'matts' are not homogeneous: they are interrupted by sandy depressions or 'intermatts', which vary in depth between 50 cm. and 2 or 3 metres. Intermatts take the form of basins or gulleys, either winding or straight, which are sometimes a few hundred metres

¹ 'La Nave Romana di Albenga', *Revista di Studi Liguri* 18, 1952. N. Lamboglia.

² 'Submarine Discoveries in the Mediterranean', *Antiquity*, No. 4, 1930, pp. 405-14. A. Merlin.

Visiteurs de la Mer, Centurion 1956 and pp. 8-16 of *Le Plongeur et l'Archéologue*, both by Guy de Frondeville.

Le Monde du Silence, Editions de Paris, 1954, pp. 117-41. J. Y. Cousteau.

Nouvelles Plongées Sans Cable, Arthaud, 1960, pp. 80-95. P. Taillez.

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long. The sides of these declivities are vertical and the bottoms curved. The phenomenon is not yet understood.

In these conditions ancient wrecks are invisible. The possible tumulus becomes confused with natural hummocks. Hidden cargoes could be located by an echo-sounder of the type which reflects layers of sediment. Occasionally, part of the wreck may be visible on the intermatt, or pottery can be seen on the walls of the declivites. This was the case at Spargi.

Excavation will be arduous, as the weeds have to be cleared and their roots go deep into the sand. The surface layer of the wreck will not only be camouflaged, but embedded in this tough, matted covering. However, such sites are of special interest to geologists and biologists since they date the natural growths.

Biological and Geological Aspects of the Problem

On ancient wrecks, concretions are the result of local biological conditions and, being of known date, are of the greatest interest to both geologists and biologists. Concretions continue downwards, white and dead, throughout the entire area of the wreck and below the sand which has gathered, thus producing a geological time scale. Given layers of sedimentation 3 or 4 metres deep, the geologist is in a position to calculate the date of each stratum from biological datings of concretions within the sand.¹

The sponges, bryozoans, calcareous plants and other forms of marine life which grow on rocks, spread to and flourish on, man-made objects which, in the end, they disguise. On a rocky bottom an ancient wreck will be entirely camouflaged, whereas on sand, even when there is the same amount of concretion, as at Cap Drammont, the wreck stands out in relief and the ship-like mound attracts every diver's attention. The amount of concretion which forms on a wreck seems to be in direct relation to its proximity to rocks. On the other hand, it is not true to say that wrecks, far from the coast and on bottoms almost free of marine life will be unconcreted.

¹ *Zuyder Zee Archaeology*, G. D. van der Heide. *Antiquity and Survival*, 1955, No. 3.

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There is a layer of water near the sea-bed which has a diminished oxygen content; on a flat bottom, the major part of a wreck rises above this sterile zone. The upper parts can be considered as a sort of oasis where growths and animals will abound and be subject to conditions very different from the bottom.

It is usually possible to deduce the way a ship has been buried by the sand. This is done by examining its relation to local submarine geology. There are however individual cases where, though the wrecks are all in places which to the layman, appear identical, their degree of relief above the sand varies enormously; such variations are of the greatest interest geologically.

The Genesis of a Wreck

The position of a cargo on the bottom results from the way the ship sank. This will become apparent, at least in part, in the course of excavation, but it is as well to form an idea of what happened before work begins, in order to make a rational plan of campaign. Visible clues must be assessed and the process of shipwreck can be considered in three distinct phases:

1. The short interval between surface and bottom. One end of the ship generally goes down before the other, at a more or less steep angle. Change in density causes partial disorder in a cargo that was stable in air. Objects lighter than water rise to the surface, or if they are tied, exercise an upward pull. Certain things will sink more slowly than the ship and be scattered around her.

If the ship sinks steeply, heavy objects may slide forward while lighter ones fly off before reaching the bottom. A certain number of amphorae are usually dispersed at some distance from the compact cargo of an ancient wreck. It must however be remembered that, in the normal way, cargoes are tightly stowed; this limits the disturbance.

2. The downward glide is suddenly arrested the moment the boat settles. The resulting shock and change of angle can again upset the cargo. The boat may strike a ledge of cliff, land like a seesaw on top of a rock, or come to rest upright on a sandy

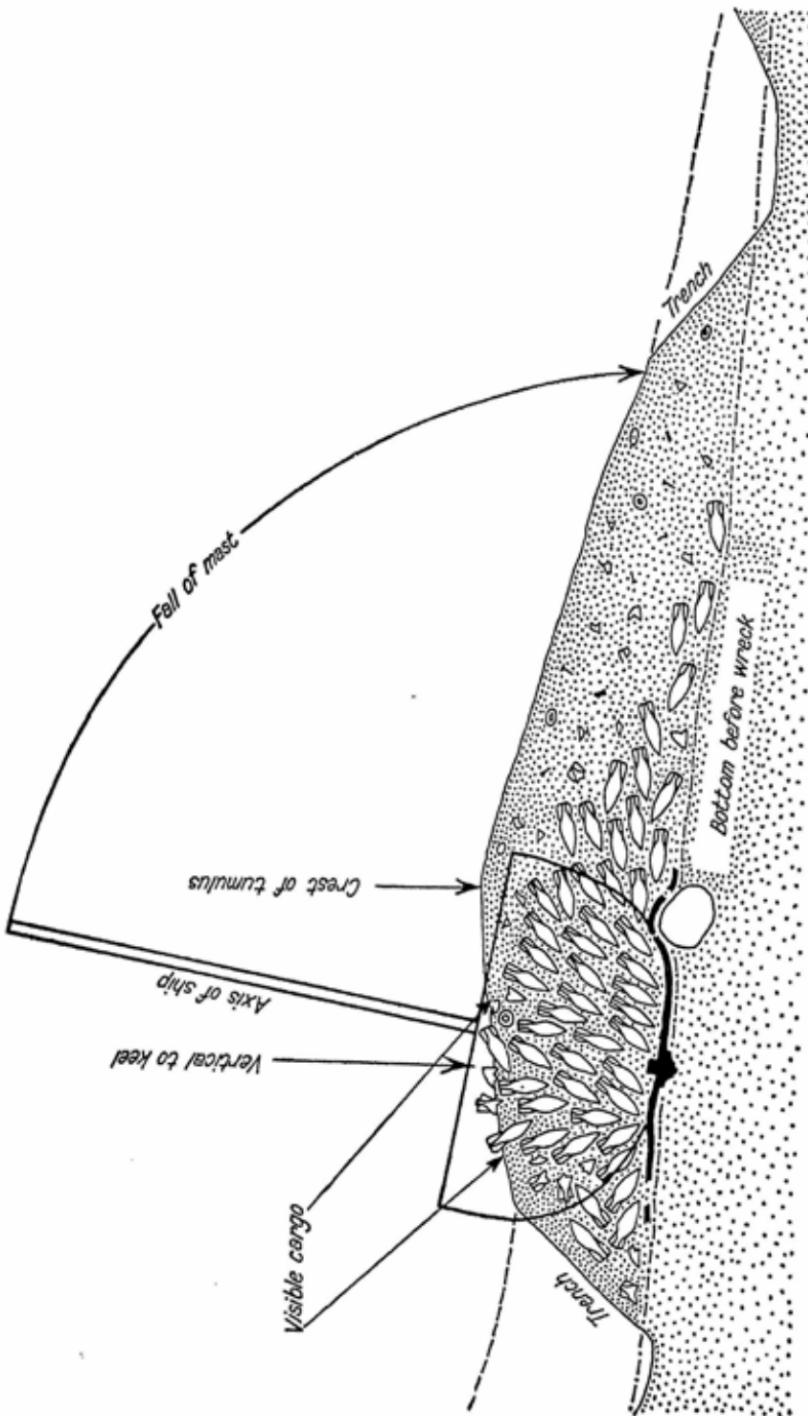


Fig. 2. Schematic section showing how an amphora-carrying ship opens when the wood becomes waterlogged. The softened hull (shown in black) takes the shape of the bottom and the amphorae fan out according to the slope; in the course of time sand gathers and a tumultus is formed. Also shown is a peripheral trench, dug round this tumultus with a powerful air-lift, in order to isolate the significant area so that excavation can be carried out in a series of well-controlled layers; the sand from each layer is pushed into the trench which is cleared periodically.

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bottom. The ultimate state of the cargo does in fact depend on the way the ship sank, how it came to rest, the nature of the cargo itself and the character of the bottom.

3. Once the hull has rotted, its disintegration and collapse under the weight of the cargo is probably the most important factor governing the wreck that now confronts a diver. The ideal wreck would be an amphora-carrier that sank horizontally on to a flat, sandy bottom. When the sides of the hull collapsed, the cargo of upright amphorae would unfold like a flower, giving a fan-shaped transverse section. Where the sea-bed slopes downwards, as it always does near rocky shores, the wreck will settle with a list depending on the angle of her keel, or axis, to the slope. When the hull gives way, the cargo slithers to one side. A soft, waterlogged hull is moulded on to the bottom by the weight of the cargo; on a hard, flat surface it will break in places and then spread out.

Finally, if a ship falls on rocks, the cargo will hold together until the wood perishes: then the cargo falls in all directions.

In shallow water, the action of the sea can be added to the factors already mentioned; storms scatter a wreck, carrying the light parts farther than the heavy.

The variety of wreck is enormous. Some may even be found in declivities which correspond in shape to the hull which, in this case, will be perfectly preserved. The hull will also hold together if the ship sinks into soft mud.

As we have only reached the border of the submarine realm, it would be foolish to generalize about all ancient wrecks. Were someone from a bathyscape to tell me he had seen a Roman ship with her sails set in the very depths of the sea, I should not be in a position to contradict him. In the Mediterranean, however, and in circumstances where diving is feasible, we have found by examining fairly recent wrecks of wooden ships, that the process of disintegration is rapid and can be considered in terms of ten-year periods.

The wreck of the *Panama*, found 1 mile off Toulon at a depth of 55 metres, is a good example of this process. She was one of the last paddle frigates, launched in 1843. The wooden hull was

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plated with copper, its length was 69 metres at the water-line, the breadth 12 metres 10 and depth 6 metres 5, with a displacement of 3,873 tons. She was scuttled in 1896. Now, only a table of mud, about 1 metre high out of which sundry almost unrecognizable objects protrude, distinguishes her from the surrounding, uninterrupted expanse of bottom.

The formation of an antique wreck does not result from a regular process of disintegration covering thousands of years. If this were so, there would be no explanation for the astonishing state of preservation of buried finds, or the even more amazing conservation of hulls.

A wooden boat when it reaches the bottom of the sea represents a supply of fresh food for worms and other forms of marine life. The banquet begins, then after a few years it ends and the boat subsides into its final position. Biological conditions are changed: nothing edible remains. The left-overs turn into a layer of mud which forms a protective covering over the bottom of the ship and its cargo. Once this has happened the mineral era takes over and lasts for centuries. Sand gradually infiltrates and packs out the protruding cargo, while water movement and plant life are still eating away at the upper parts. In a thousand years the wreck of the *Panama* will hardly have changed; only after millennia will all the surface remains be either buried or disintegrated. In that remote future the hummock of mud will hardly arrest a diver's attention.

This process can be seen again at Navarino. In that sheltered Mediterranean bay, the cliffs continue under water, sloping steeply to a depth of 40 metres. Between the surface and the base of these cliffs, the rock disappears beneath enormous pieces of rotten wood. It is difficult to distinguish an individual wreck within the area which covers several hundred metres. The famous naval engagement took place in the year 1827.

Conditions in the Baltic are entirely different: the water is less salt, marine life less plentiful, there are no teredos, or xylophagous worms, and the bottom is soft and muddy. In consequence, the hull of the *Vasa* was found to be solid and astonishingly well preserved.

The galleons sunk in Vigo Bay, in the Atlantic, are well documented. According to Hypolitus Mangin (1873) and Robert Stenuit (1958), it seems that the hulls are deeply sunk into mud: they are consequently well preserved and still hold their shape.

It is impossible to generalize about the state of preservation of wooden ships in different seas, but quick burial under sand, due to strong tides and currents helps to preserve them.

In the Atlantic, underwater archaeology would be more difficult than in the Mediterranean, owing to those same tides and currents, cold, muddy water and the fact that the wrecks would be so deeply buried. On the other hand, supposing ancient wrecks were found there, they would be in an excellent state of preservation.

Red Sea wrecks, whenever they have fallen near reefs, are masked by profuse coraline growths; elsewhere the calcareous sand produced by marine life would be considerable.

Invisible Wrecks

Most antique wrecks found to date have been marked by their cargoes of marble, or pottery, which defied the disguises of sand and concretion. On the other hand, ships which carried perishables, metal of no great bulk, or warships which have no cargo, are bound to be difficult to find. From my own small experience, I consider that it may be easier to detect such wrecks on a bottom far from the influence of the coast.

The Bronze Age wreck, or rather cargo, at Gelidonu Burnu was small and consisted entirely of metal, largely hidden under concretions. In this most exceptional case, the cargo was only distinguishable because it lay in the middle of a rocky saddle swept clear of sand by a strong current. Had this same wreck landed at the foot of the usual offshore rock-fall, it would have been entirely buried in sand. But again, had it fallen at Mahdia, on a hard, flat bed of open sea, it could have been seen at a glance.

Let the reader have no illusions about electronic detectors, supersonic sounders, Asdic and so on. The scope of these instru-

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ments is limited to large masses standing out in strong relief against a flat bottom. If a boat equipped with such a device did happen to pass over an ancient wreck buried in sand, there would be very little chance of detection. Some instruments are more sensitive than others, but their range is relatively less; to explore even a limited zone with one of these would be an arduous business.

At present, there are more known wrecks in the Mediterranean than could possibly be excavated in twenty years, even by constant and concerted efforts on the part of archaeologists. Free divers find new ones every year. In the western Mediterranean wrecks are pillaged or subjected to so-called excavation. The problem is not to look for more (though each dot on a chart has meaning in relation to ancient trade routes), but to protect and control the excavation of existing sites.

Causes of Shipwreck

On wrecks where I have worked, visitors are invariably fascinated by the surface accident rather than the underwater processes which would explain the remains. The topic smacks of sensationalism because, apart from fire on board, which would leave traces, the nature of the disaster leading to such serious consequences is bound to remain hypothetical.

Ancient ships were wrecked for reasons which can best be expressed by statistics. In open sea, a sailing ship goes down either because there is a fire on board, because she keels over in a storm, or because being disabled she fills with water; the possibility always remains that a merchant ship may have been sunk by a ship of war. Near the coast, storms or even strong currents without any wind can hurl a defenceless sailing ship against the shore. Damaged rigging may have the same consequence. A navigational miscalculation on a dark night or an unsuspected shoal can be fatal and lastly, a ship can break her moorings or drag her anchors in bad weather and end in disaster. For every wreck that satisfies one of these considerations, one may still ask oneself whether the boat was not being pursued by a pirate and beached purposely, in order to save the crew. It is as well to

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search in the vicinity of a wreck for anchors, to find out whether any attempt was made to moor the ship and avert disaster. However, so many antique anchors litter the shores of the Mediterranean that it is difficult to be certain whether one, lying a few hundred yards from a wreck did in fact belong to it.

Choosing a Wreck for Excavation

When the excavation of a wreck is being considered, archaeological interest should not exclude all other factors. Shelter from the prevailing wind should be kept in mind, because working time can be calculated according to the degree of exposure of the surface above the wreck. This may vary between a few days per year or on exposed reef, to daily dives in sheltered roads. Unfortunately, wrecks are more likely to be found in exposed rather than sheltered places. Then there is depth: shallow wrecks in 0 to 15 metres of water are likely to have disintegrated. At about 40 metres work becomes more delicate, difficult and dangerous. Increased depth restricts diving time and in turn, this necessitates a much larger and more skilled team of divers. Deeper than 40 metres, scientific excavation is impracticable, though the salvage of objects is still possible. Proximity to a port, with all the advantages which this situation implies, is a factor well worth considering. The nature of the bottom counts, because wrecks on sand or mud are much better preserved; on an uneven rocky bottom the cargo will have been disturbed and damaged by the abundant marine life. Current, unless it is very strong, which is rare in the Mediterranean, can be of considerable help in excavation, as it clears the cloud of mud caused by digging.

II

Wreck Excavation

Prospection Before Excavation

WRECK excavation is a long and costly business. Even the salvage of objects such as was started eight years ago on the Roman cargo ship at the Grand Congloué, has not been finished at time of writing. If scientific method were applied, with all that it entails in the way of plans, drawings and photographs, the satisfactory excavation of an average amphora-carrier would run into years, especially when one takes into account the delays caused by heavy seas. Land archaeologists may propose that aims be limited to a small area of the wreck, but this is not easy under water; the pros and cons of this proposition will be discussed later.

Excavation of large ships involves the removal of vast quantities of sand. For example, a buried Roman merchantman, represents 400 tons of objects mixed with roughly another 200 tons of sand and say, 600 tons for the boat itself. Excavation of the wreck-tumulus by trenching the periphery (taking into account the slope and consequent equilibrium of the sand), would mean the removal of the same weight again, roughly a total of 1,200 tons.

Were this task to be undertaken without thorough understanding of the site, and a logically predetermined plan of campaign, we should be forced to examine the 600 tons of sand from the peripheral trench with the same minute care as that

applicable to the significant areas. Expert examination of the site allows the more logical approach, whereby powerful mechanical methods can be safely applied to the disposal of pure sand and the archaeologist's time and energy be concentrated on the significant areas. This problem of expertise does not arise on land, where tombs were dug and towns built by men adapting their technique to local soil conditions; and where there is therefore a relationship between natural substratum and man-made structure. The relationship of wreck to bottom is accidental. Geological laws govern the nature of the sea-bed. The physical climate and biological structure vary considerably from one place to the next, even along the same coastline. The success of an excavation and the technique adopted depend on an expert analysis of these natural phenomena. Since the wreck itself will have modified the structure of the bottom, so the surrounding sea-bed must be examined. There will also have been a natural change, in the course of the centuries since the ship sank. The expert will have to judge conditions existing at the time of ship-wreck. This requires comparative knowledge; even then the prognosis may have to be confirmed by certain mechanical tests.

Soundings

On land, it is possible to dig a narrow trench with vertical walls. To attempt a similar sounding on a wreck would result in a hole like a shallow inverted cone, which would defeat its purpose. A disproportionate amount of evidence would be destroyed in order to examine a possible few centimetres of wood at the bottom. Sand, which is light and mobile under water, only reaches equilibrium on a gradual slope. Harmless little soundings can be made by hand, only if the wreck is spread in a thin layer and does not continue in depth below the sand.

My own solution to this problem is a core-sampler. Oceanographers have known these instruments for some time and more recently, geologists have used them for detecting petrol under the sea-bed. The choice of an appropriate sampler depends on the type of bottom to be cored: whether rock, mud or sand. Sand,

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which is our problem, is the most difficult material to core. I have gone into the matter with specialists and all agree that coring on an ancient wreck, in the circumstances I described, is feasible. The satisfactory core-sampler remains to be found: the Russians have one, the Americans another and one is being developed in England.

The Analysis of a Wreck

In order to understand a buried wreck, to be able to dig in the right place and to have a basis for future reconstruction of the finds, the following points have to be established at the outset:

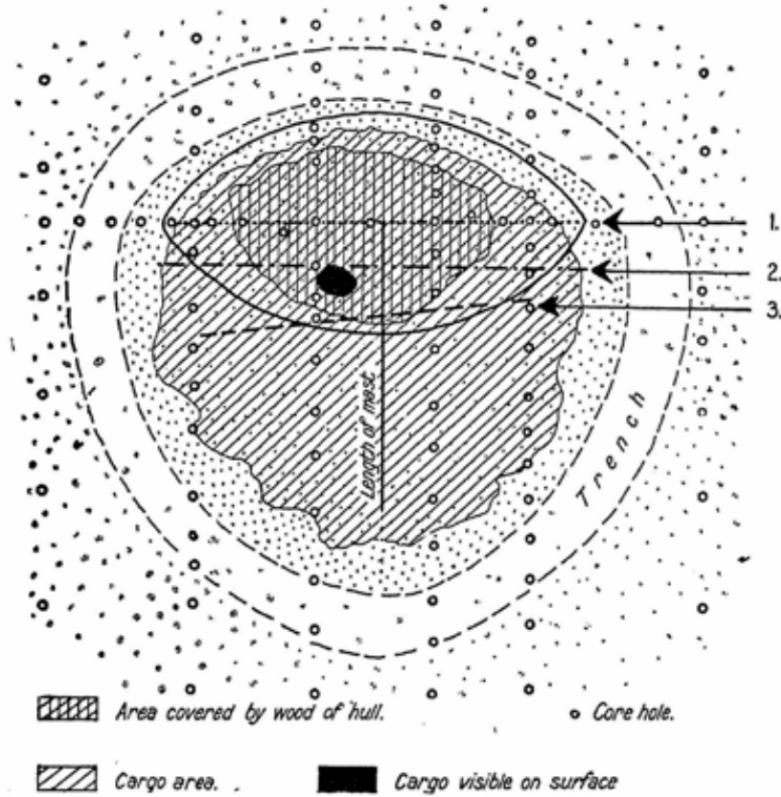


Fig. 3. Schematic plan of a buried wreck-area (see section, Fig. 2). After a preliminary analysis which has been tested by coring, a trench is dug with the air-lift, around the significant area. Arrows: 1. axis of buried keel; 2. surface intersection of plane through mast and keel; 3. visible crest of tumulus.

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The axis of the visible wreck-mound (usually its crest).

The keel axis: this should be found before digging starts. It can best be done by sounding with a core-sampler.

The area of spilt cargo, below the surface.

Lastly, the list of the boat before collapse, or an axial plane taken at right angles to the keel. If the boat came to rest upright, this plane must correspond with the axis of the keel; but if she listed, the plane will be more difficult to determine, though it may emerge from the excavation and reconstructions.

The average wreck appears on the bottom, as a tumulus. The axis of this mound is the first thing to establish and it is fairly easy for a trained eye to distinguish. Once this arbitrary axis is found, the next thing we need to know is whether the ship listed when she settled on the bottom, before the hull was flattened, the cargo split, and the whole buried in sand. The list, however slight, will have caused the basic asymmetry in the relationship of the remains. The rigging will have fallen in accordance with this list and the minimum area, which we must regard as sacred and must reserve for careful examination, will lie to one side and be at least as long as the mast. Objects once on deck will also be found to this side, sometimes beneath the cargo that spilled over them. The opposite side will be proportionately smaller and far more clearly defined. Finally, it is underneath the side that listed that the flank of the ship will be buried.

A diver sometimes comes across small groups of broken amphorae. Occasionally they have every appearance of being a recent deposit. Such things are difficult to evaluate; have they come from a dispersed cargo? From a small boat carrying only a day's supply? Or do they indicate a larger, buried wreck? In some wrecks, the top layer of cargo may be scattered over a wide area, so that there is no way of telling where the ship itself is buried.

In every case a few cores would give the answer without damaging the potential excavation. A line of cores taken inwards towards the site, would first show a section of the natural

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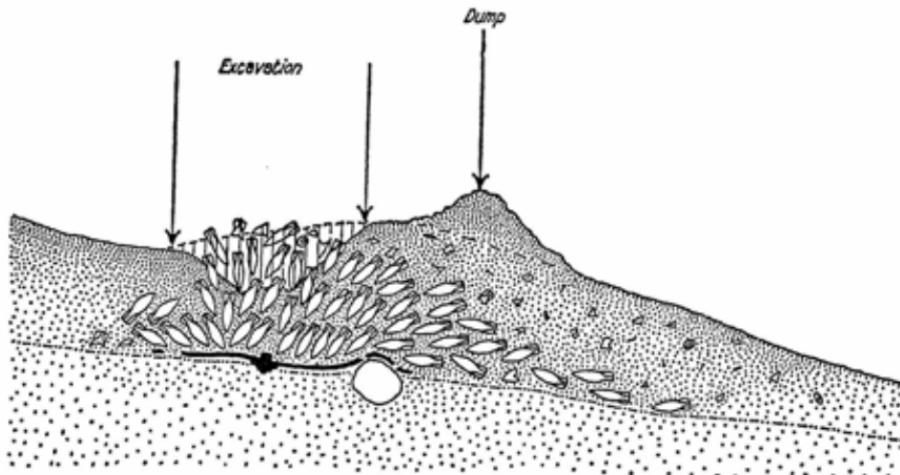


Fig. 4. Wrong method of excavation: a hole has been dug into that part of the tumulus where amphorae necks showed above the surface of the sand, with the resulting dump made over the actual cargo area. When this is done the cargo cannot be removed in consecutive layers and recording becomes impossible.

bottom, which it is essential to understand. Then they would indicate the limits of the cargo area. Since wrecks are usually deeply buried, a large trench is the only alternative to coring. In the past, many serious mistakes have been made through ignorance of these boundaries, the most usual being to dump on top of the wreck itself; this happens on land, but under water where working time is restricted, it is fatal and if cores are taken, unnecessary.

Cores taken across a known wreck area would show the nature and extent of the cargo: the number of layers of amphorae, for instance. They might well indicate the construction of the hull, whether it had single or double planking, with or without lead plating, its state of preservation and whether there was a deck. They might even tell us which part of the hull we had struck. Ideally, two transverse lines of cores across a wreck would show the axis of the keel and the lie of the cargo, that is to say, the list of the ship.

If, after prospection, excavation were not judged to be worth

while, analysis of the core samples would still provide a minimum of valuable information about the wreck and allow it to take its place on a marine chart in relation to other ships of the same period.

Value of a Specialized, Supersonic Echo-Sounder

Specialized, supersonic echo-sounders are coming into use on oceanographic ships, for the study of marine sediments. Their waves penetrate the bottom and are partially reflected by successive layers. These reflections are recorded on paper and give a section of the soil structure. It would be interesting, during prospection, to try such an instrument on a wreck to see whether it could give an idea of the section. However, these electronic devices (which will be discussed later) are costly and hardly out of the experimental stage, whereas a simple mechanical corer would come within the range of an excavation budget.

Past Mistakes

When divers, acting as self-appointed archaeologists, first came across groups of amphorae half buried in the sand, they had no idea of the size of a wreck or its probable depth below the surface. They started to excavate by removing the visible jars then, seeing that there were others, they installed an air-lift to disengage the lower layer. This amounted to no more than the salvage of objects and the result of their efforts was a big hole in the middle of the wreck area. The man on the air-lift inevitably continued to enlarge the hole as new amphorae were revealed around him. Salvage connotes profit, so that divers wanting quick returns chose the most powerful air-lift they could find. This was bound to damage fragile objects like delicate pottery, organic matter and the wood of the hull.

When the sea-bed is almost horizontal, this method quickly lowers the wreck area in relation to its surroundings. At this stage, when the objects were held in loosely packed sand the divers would change over to a water-jet which they used to clear individual finds. This potentially excellent instrument serves no good purpose at the bottom of a hole, where it merely

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blows sand from one place to another. Such a primitive technique gave no control over the excavation nor could a draftsman make records.

Excavation Method

Despite considerable experience, it is still too soon to define a procedure applicable to every ancient wreck. The few criteria we can formulate, should not preclude improvisation in special cases.

In considering the difficulties inherent in underwater excavation owing to its lack of precision in comparison with land work, one is tempted to suggest that wrecks should be raised in a single block and dissected under normal conditions. This is obviously impracticable in the case of a large ship and for a small boat it would be disproportionately expensive. It has been suggested that air bases could be made by freezing artificial icebergs. The idea remains theoretical, but it could be taken up again on a more modest scale, in order to freeze limited portions of a wreck which were too delicate to excavate under water.

As things are, we have to apply land techniques, modified to suit underwater conditions: plans, drawings and photographs must provide the evidence for eventual reconstructions.

Free-Standing and Buried Remains

The Drammont wreck consisted of amphorae welded together by a crust of concretions, in the shape of a ship. When this crust was removed, we were faced by bare sand under which the wreck continued in depth (there were in fact three layers of amphorae above the hull). Ancient wrecks may be entirely free-standing or entirely buried and every intermediary stage is possible. A different excavation technique has to be used in either case, or on free-standing and buried parts of the same wreck.

Free-standing objects, surrounded by water, are so distorted by concretions as to be almost unrecognizable. Concretions develop and join separate objects into one solid block. Small, loose concretions which contain artifacts can also be found scat-

tered on, or in the sand. Within these concretions bronze may have become powdery, while iron disappears completely, leaving a mould of the original shape.

It is impossible to deal with concreted remains under water; they have to be lifted and studied on land. Lumps must be detached according to their lines of least resistance and not with regard to their possible contents. If this is done carefully, the breaks can be fitted together again on land.

This gives rise to certain recording problems. Underwater photographs of complex concretions will be almost impossible to interpret. Even the draftsman, with his trained and selective eye, may not be able to fill the gap. He will be faced by quantities of baroque shapes covered by growths of weed, sponges and gorgonia, nor will he be in a position to foresee the possible breaking points within the complex—if indeed the breaks turn out to be clean—so that his drawing of any one portion, will not necessarily correspond with the actual mass which is broken. It will have to be drawn again on the wreck before it is raised and yet again on land. When laid on the ground, it will be almost unrecognizable in comparison to the position it had when its equilibrium was dictated by other free-standing concretions. The only solution is that the diver who is responsible for actually detaching the lumps, should mark each as it is broken. Despite difficulties, particular attention should be given to these surface concretions, as it is here that the components of the rigging will be found, though they themselves will, in turn, be difficult to interpret.

In the buried portions of the wreck, conditions will be more analogous to land, with the difference that sand will be lighter and less controllable; it can be displaced by a wave of the hand.

Excavating by Peripheral Trench

After years of experience, I have come to the conclusion that, once the limits of the wreck have been established below the sand, excavation should start by further isolating in relief that area which contains the remains, by means of a peripheral trench dug by the powerful machine known variously as a 'suction pump'

or 'air-lift'. This would have the effect of making the wreck stand higher than its surroundings, with its walls sloping at that angle at which sand is in equilibrium. The object of this procedure would be to produce conditions in which it would be possible to excavate from the surface in progressive layers; thus avoiding the unsatisfactory hole with sloping walls, yielding a section of several metres at the top and a few centimetres at the bottom. Air-lifts work best on pure sand. Over a wreck they are apt to become obstructed by sherds and other foreign bodies. Moreover, a powerful machine cannot be prevented from damaging delicate finds.

The abilities of individual divers vary enormously: some can do heavy work under water but are incapable of performing delicate operations. The function of such people could well be to make the peripheral trench with an air-lift, under stern caution to stop at the sight of an object in the sand.

The delicate work of clearing sand from the cargo can either be done by hand, or mechanically, with a water jet. In some cases it may even be expedient to suck the sand away with a miniature air-lift. Each successive layer of cargo would be removed after it had been recorded.

Buried Parts

The disposition of the cargo becomes apparent as the excavation progresses, and this may mean modifications in the work. The problem is to know whether a particular area that has been uncovered, is going to remain stable while the rest of the level is cleared. Water is so much denser than air that its slightest movement affects the bottom which, relative to its surroundings, behaves as though it were light. There must be an experienced diver on the dig who can assess the swell, waves, tides or currents, and direct the work so that instead of destroying what is being done, water movements are used to an advantage. Objects buried in sand are well preserved: once cleared they can be photographed and a draftsman can work quickly and without difficulty. On the other hand, sand is displaced even by the diver's own movements and will travel farther than he thinks.

It will fall back in an instant covering objects which have just been cleared for recording.

Relief, within any one level, must be controlled in such a way that water movements can do no damage. Sand runs into the smallest cracks and if these are in delicate organic matter, it is best left there until the surroundings have been levelled and the balance restored. An archaeologist who dives, may have but small experience of the sea and be tempted to consider sand as his enemy. I have heard it said that 'the wreck is not archaeologically clean'; a remark which may have some significance on land. We owe the preservation of a wreck to sand. It is sand that has assured its stability in time and space. When sand is removed, fish rush to the spot like birds searching for worms on a newly dug garden, but they are very much more destructive than birds. They burrow like pigs for truffles and the archaeologist need not be surprised to discover, from one day to the next, that a certain corner of the wreck has changed its appearance. It is prudent, between times, to cover with a weighted plastic sheet those parts which contain fragile organic matter. Spear-fishing is seldom practised on submarine sites, a fact which is very soon appreciated by fish in the vicinity. Curiosity as well as hunger attracts them to the wreck. After a while they lose all fear, groupers in particular become almost a nuisance.

In order to excavate in controlled layers it is essential to understand the behaviour of sand. It is not always easy to maintain the concept of a phase or a layer in the disordered cargo. An upright amphorae is three times higher than a horizontal. To keep an even surface in a cargo of tumbled jars is wellnigh impossible and little things like lead rings and coins keep slipping into crevices.

In the course of excavation, a mass of such delicacy and complexity may be revealed that it is impossible to record or examine it under water. In this case we should pause and consider whether, if its size permits, the mass should not be raised in a single block. In the case of a wooden chest containing shapeless organic matter and fragments of cloth, for instance, we can, while disengaging it, construct a frame of planks and eventually raise both casing and contents.

Partial Excavation

Since excavating an entire ship is a vast undertaking, it has been suggested that research should be limited to one small area. To this I would say that a wreck cannot be compared to a *tell*. It is an organism in which each part is necessary to the understanding of the whole. The cargo may not be the same from stem to stern, or again, it may be so disturbed that the necessary data for reconstruction can only be obtained after excavating the wreck as a whole.

In partial excavation, the archaeologist would be confronted by even more serious material difficulties. The chosen area would have to be limited by retaining walls. Even with a fool-proof method of sounding, it would not be possible to have exact foreknowledge of the significant subdivisions, and retaining walls might have to be moved. In fact, any attempt at limited excavation would so damage the parts that remained, that the archaeologist would not be in a position to 'leave them to posterity'.

Relationship of Cargo to the Size of the Ship

The relationship of an indestructible cargo to the ship is very apparent. It is a useful standard of comparison when taken together with the structural remains. When, as may sometimes happen, the hull is reduced to fragments, the size of the ship can still be judged from a cargo such as amphorae, statues or architectural components of marble.

Width: cargo is stowed solidly from wall to wall in a ship. If it were otherwise it could not be kept in place. Consequently, it is always possible to form an idea of the width of the ship from its load. There may be transverse divisions, but within these the load is even, from side to side.

Length: wrecks on the bottom often have the shape of a ship, that is to say they taper at either end. This presupposes solid loading from stem to stern and in such cases, the cargo gives the length of the ship. Of course, this is not always the case, there may be several holds, some filled with perishable cargo and others empty.

Depth: I once saw, in North Africa, a boat with a load of earthenware jars that reached half-way up the mast. This gave me to think on the relationship of a cargo to the draft of a ship. The maximum weight of metal would hardly fill the bottom of the holds whereas amphorae might protrude above deck.

Visibility

Mediterranean water is usually very clear but seemingly unadulterated sand always contains an admixture of mud. When excavation starts mud rises at the diver's first gesture and as work proceeds, it soon covers the site. This cloud seldom rises beyond a metre or so. A current, if it is sufficiently strong, helps to keep the water clear. When the diver faces into the current he can still work in moderate visibility.

Two divers working separately, but in the same area, will be enveloped in a thick cloud. Bad visibility necessitates careful organization and apportioning of tasks. Photographs and drawings should be made in the morning before any other work and again later in the day, but only after a pause. Sometimes an interval has to be allowed between each separate dive, whatever its object.

Submarine light is diffuse and monochromatic, diminishing relief and the characteristic colours of individual objects. The eye accustomed to associate form with colour and cast-shadow, will have difficulty in distinguishing artifacts from natural forms. This can be remedied by a powerful electric lamp on the bottom. Artificial light reintroduces colour and relief, and vision returns to normal. The expedient is particularly useful to inexperienced divers who, while they have not yet developed underwater vision, may be hardly aware of their maladjustment.

For the same reasons, classic black and white record photographs (which should always be taken by flash to give cast shadow), must be supplemented under water by colour photos which any non-diver can interpret.

Wood

The bottom of an antique boat is usually both protected by the cargo and buried in sand, so that we may expect to find it in an

excellent state of preservation. It should always be possible to record a significant length of keel. The wood will be water-logged, but not distorted, though broken in places, when flattened by the weight of the cargo. Even so, the parts will have a visible relationship. The entire lower portion of the hull can be examined, that is to say: the jointing of ribs to keel, the number and shape of galleboards, the keelson (these vary considerably in size), the joinery of the planks and the lead sheeting.

Naval architects have been puzzled by samples of Roman ships which they have seen as a result of underwater digging. Individual parts seem small in relation to the evident size of the wrecks from which they come. The paradox is however explained, when we examine the extraordinarily skilful joinery of the planks themselves which were fixed, edge to edge, by quantities of wooden tenons which gave the structure its strength. Moreover, ancient ships may have been reinforced in the upper part of the hull.

The edge-to-edge joinery of planks by tenons in mortises gives rise to repair problems. I cannot see how a plank could be replaced in this type of structure; I should, therefore, be particularly interested to find, preserved in sand, a portion of a Roman ship which had been repaired.

It would be unusual for a ship to come to rest on its side and even less likely that it should fall keel up, but we may hope that one day wrecks will turn up in these positions, so that the top parts will be protected and divulge the secrets of their walls and decks.

Conclusion

Even to the expert, each wreck is a new problem. Its excavation is an enormous undertaking: complex, long and costly. In consequence, the method of attack has to be carefully planned. Even so, experience shows that the plan may have to be modified in the course of excavation, which implies a grasp of diving craft on the part of the man in charge.

It is only after long experience of underwater work that one may hope to foresee the course of events: the sum of the work

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involved, the equipment it will require and the variations which are likely to crop up. Only experience can give the necessary flexibility which will allow mistakes to be remedied. It is, in fact, the essential qualification for directing underwater work.

Until such time as a coherent excavation technique has been evolved and put into practice more than once, on different types of wreck, a non-diving archaeologist or even one who has just learned how to dive, will find that it is to his advantage to use the services of a professional. This professional must have experience of this particular type of problem and a comparative knowledge of ancient wrecks.

To an archaeologist, a wreck is a closed group that was once contained within a ship's structure which is itself of interest. The hoard will be of a quality rarely to be found on land, but to the new race of amateur divers it has appeared, up to now, as treasure-trove. When a scientific method of excavation has been established, as it inevitably will be, then wrecks will have to be subjected to some form of control and preliminary inspection by an expert. In comparison with other forms of underwater archaeology, such as charting sea lanes (from wrecks and anchorages) and port work, the actual excavation of wrecks will of necessity be rare.

III

Personnel and Equipment

Team and Boat

It is impossible to devise an excavation programme for all underwater sites; their variety is such that it is even unrealistic to attempt classification and alternative schemes. However, since the subject is new and its problems not appreciated by those accustomed to working on land, it is worth stating tentative figures, as a guide. Excavation of a large and ancient wreck at a depth of more than 30 metres necessitates sizeable teams, working both on land and under water.

Divers and Field Workers

The diving contingent must include:

An archaeologist.

A professional diver who is also a first-rate seaman.

Draftsmen; four is a minimum, six would be preferable.

Two photographers (draftsmen should also be capable of handling underwater cameras).

Mechanics: two men will be required to maintain and work the compressors and other machinery. When a diving boat is used, these will be drawn from existing crew.

A marine biologist and a geologist.

Ten to twelve divers, capable of helping photographers and draftsmen. Half their number may be amateurs.

Use of Amateur Divers

Archaeologists, more than most people, are aware of the irritating aspects of amateurishness. Nevertheless, they have no option but to use free labour since modest, not to say inadequate budgets are their lot. For submarine excavation it is both easy and tempting to call upon volunteers. Vast numbers of amateurs will be delighted to offer their services. Their goodwill and devotion are evident, however they do present a certain danger. Those who do not grasp the implications of underwater excavation and at the moment, I am unfortunately obliged to class archaeologists in this category, have a tendency to believe that once a boy can get under water and stay there happily, he becomes a useful working diver. A gulf separates the amateur practising his sport sporadically as a spear-fisher, photographer or by excursions dignified by the name of 'exploration', and the professional diver with a grounding in all the techniques involved in underwater work. Nevertheless, an underwater expedition should include some amateurs, from whose number future professionals will be drawn. If disaster is to be avoided, it is essential to keep the balance and of course, to use volunteers only as assistants to professionals.

Land Team

This team will be much the same as on any other type of excavation where finds have to be registered, drawn and photographed. Only preservation presents different problems; some can be avoided if the site is near a town where museum and laboratory facilities are available to receive the objects lifted, at the end of each day. Failing this, a field laboratory has to be set up at a base where there is a plentiful supply of fresh, running water and where tanks can be constructed to take the finds. Extra personnel may be necessary to help with cleaning.

The Boat

About twenty people will always work on the site, not counting visiting specialists. This, in itself, warrants a large and comfort-

able boat of between 150 and 300 tons. Over and above personnel, the boat has to accommodate high- and low-powered compressors and other excavation machinery which can only be squeezed into a small space to the detriment of efficiency. During the months of uninterrupted work, over-reduction of living space is a false economy. When a wreck is near the coast, it is sometimes possible to make do with a smaller boat, as bottles can be charged and the high-powered compressors and other equipment not in use can be left on land. A skeleton crew suffices to manœuvre the boat as divers can, between times, do most of the jobs on deck.

There must be a dinghy with an engine capable of travelling slowly so that if search has to be made for an object in open sea, a diver can be towed under water at a speed not exceeding $2\frac{1}{2}$ knots. Again, if the mooring is exposed, large objects may have to be towed to shelter under water before they can be taken on board. The big boat must, of course, be equipped with some sort of lifting machinery. Lastly, allowance must be made for spare deck space for operations such as sifting sand from the air-lift and unloading baskets full of amphorae.

Moorings

It is of the utmost importance to maintain a fixed position above the site. Dropping anchor is out of the question, as the boat would be in a slightly different place on each consecutive day and even during work, it would shift with every changing wind or current. In practice, the problem is reduced to methods of mooring and a fixed mooring is effected by dropping two anchors or dead weights at either end of the wreck area, in line with the prevailing wind, or current, if this latter is the dominant influence. A cable is attached at one end to the weight and the other to a surface float. Sometimes conveniently placed rocks can be substituted for weights and there are sites where four moorings may be necessary. In any case, the boat will arrive each morning, pick up the floats and moor automatically between fixed points; thus, even in open sea, there will be no difficulty in finding and remaining directly above the site.

Shot Line

Divers should be provided with a line between the boat and their place of work. This saves time going up and down and gives a stable stopping-place for decompression. In current a line is indispensable. On the bottom, free divers have the advantage over men wearing standard apparatus. The helmeted diver, while working in current, is subject to a constant pull from hose and lifeline. Near the surface the position is reversed, for the free diver becomes no more than a swimmer hampered by heavy weights and can be swept away by the current, whereas the standard apparatus diver is attached to the boat by his hose. The shot line must be fixed to a rock or dead weight at some central part of the wreck and on the surface to a float, which is taken aboard each morning as the ship moors.

THE AIR-LIFT, EMULSION OR MAMMUT PUMP

General Considerations

This instrument displaces mud, sand or gravel by suction and is not sold on the commercial market. Local requirements vary to such an extent as to necessitate the construction of a suitable pump for each individual site. Essentially, these machines are intended to lift liquid, with or without an admixture of solids to a certain height above ground. Their principles have occupied engineers for some time and a superabundance of mathematical formulae results for, on a theoretic level, the problem is complex. Air-lifts were current long before free divers used them on ancient wrecks, but in the absence of any guide or manual for their adaptation to archaeological requirements, it is hardly surprising to find that divers have come up against difficulties and some have even assumed that they have invented the machine themselves. A form of air-lift has emerged from recent applications of the principles; and this now tends to be regarded as standard, but we are still far from having exhausted the possibilities of these instruments, applicable to so many different ends.

The Principle

When air is forced into the bottom of a half-submerged tube it causes, within the tube, an air-water emulsion which rises until the pressure of the column of emulsion equals at its base, the pressure of the water at that same level. Thus where d is the density of the water and d' the density of the emulsion: within a tube submerged at a depth of h , the level will rise to h' or

$$(h + h')d' = hd$$

If the height of the tube above the surface is h' , there will be no discharge of the emulsion. Maximum discharge occurs when the tube debouches on the surface and consequently h' being *null* hd is at its most powerful in relation to $(h + h')d'$.

In wreck excavation, the aspirated matter does not have to be raised to any appreciable height above the surface, and thus the air-lift discharges in favourable conditions. These surface discharges mean that the power of the lift depends on $hd - hd'$. If the depth of the lower end of the tube increases, while the upper part remains on the surface, the difference between $hd - hd'$ is increased. Consequently the deeper the site the more powerful the air-lift.

Small air bubbles grow and merge with each other in the course of their ascent within the tube; the largest have the greatest speed and momentum. This process results in the formation of piston-like bubbles which disaggregate owing to the movement of the liquid, then the process begins all over again in various indeterminate levels in the tube, provoking turbulence within the column of mixture. The discharge will be regular or intermittent, according to the way the air supply is generated. Opinions differ as to whether a regular discharge of air, or piston-like bubbles, would produce the best performance. When the input of air is stepped up, the discharge of water increases until it reaches a maximum, then it dwindles. It would seem that a maximum discharge results from a supply of air, the pressure of which is only slightly greater than the water pressure at the lower end of the machine. As the discharge of air has to

PERSONNEL AND EQUIPMENT

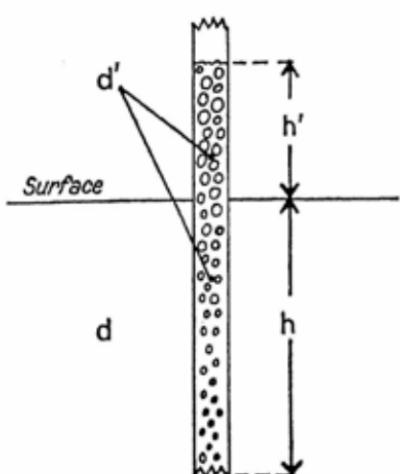


Fig. 5. Schematic section of an air-lift pipe showing action of bubbles.

be controlled within a certain amount, the pressure will be regulated according to the compressor's output in relation to the length and diameter of the tube. It is estimated that the discharge-weight of water momentum is about ten times that of the solids to be lifted.

Application

An air-lift consists of a rigid, or half-rigid and half-pliant tube into which compressed air is introduced at the lower end. The

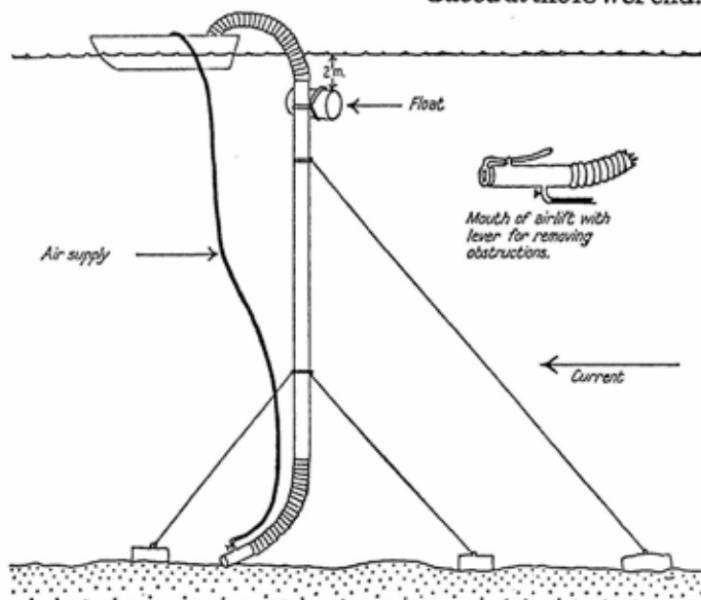


Fig. 6. Diagram to show how an air-lift is usually rigged.

speed of ascending bubbles within the tube increases in proportion to its diameter; too narrow a tube will result, among other things, in an insufficient output. Let us take a diameter of 120-150 mm. The diameter must remain constant throughout the length of the pipe, the slightest narrowing provokes blockage. The vertical portion of the air-lift can be made of steel piping; this gives excellent results, its only disadvantage being a tendency to rust. The lower part has to be pliant and can, for instance, be made of reinforced rubber; there will be a rigid mouthpiece at the extremity. Stones and sherds tend to get stuck in the nozzle and are difficult to dislodge by hand. It is therefore as well to affix a ring, slightly smaller in diameter and hinged on to the nozzle, which can be opened and shut by means of a lever. This gadget limits the size of objects swallowed and by moving the lever, the larger obstructions are pushed out of the suction area and drop.

Portable Air-Lift

A portable air-lift can be most useful for delicate work or small soundings. It is made of a single rigid tube 4-5 metres long and 80-100 mm. in diameter. The diver holds this tube in as nearly as possible a vertical position, braced against his shoulder.

Air Supply

A compressor with an output of around 120 cubic metres of air per hour, under pressure of 9 kgs. per square centimetre is required to work an air-lift with a diameter of 120-150 mm.; that is to say the heavy type of compressor we see on road works, powering a pneumatic drill. If the boat is too small to take such a large machine, several portable compressors can be combined and harnessed together. These will, of course, cost more than a single, standard compressor. The hose which feeds compressed air into the tube must have a diameter sufficient to ensure that loss of efficiency over the entire distance will not be large enough to affect performance. In practice this means a diameter of 20-30 mm. Connection between this hose and the mouth of the lift, at the end of the pliant extension of the large tube, is effected by

means of a tap which enables a diver working on the bottom, to reduce or turn off the discharge of air.

Installation

A powerful air-lift is both cumbersome and heavy, yet its mouth has to be wielded with precision; all things considered, it is best to make a semi-permanent setting rather than to put the contraption into the water every morning. This is done by attaching the topmost extremity of the rigid tubes to a metal float; an oil drum, for instance, with a capacity of 200 litres is suitable. There must be a hole in the bottom so that it can be filled with air and a tap on the upper part to release the excess if the air-lift is too light. Two weights of 100 to 200 kilos are placed on that part of the sea-bed which is to be cleared and the lift is moored between them by cords tied 6 to 10 metres above the mouth. By regulating these cords the machine can be displaced along a line between the dead weights. The total length of tubing is so calculated that the uppermost extremity, held by the float, shall be at least 2 metres below the surface and relatively protected from the movement of waves. The weight of an air-lift in water can be adjusted by regulating the amount of air in the float, always keeping in mind that the machine will become more buoyant when in use. The angle of the rigid pipes should be as near to the vertical as possible, never exceeding an angle of 15 to 20 degrees; this, because sediment will deposit on the walls of the tubes and block the machine. Usually the float suffices to hold the machine in position, but if there is a strong current the tubes have to be held by shrouds, fixed to four dead weights on the bottom (see fig. 6).

Inspection and Disposal of Matter Lifted

My own views on excavation method, as stated above, preclude the use of air-lifts inside the wreck area, unless the machine is modified for this type of work; even so, I would consider it dangerous except in the hands of a professional who has experience both of air-lifts and wreck excavation. However, it may sometimes be necessary to examine matter coming from the

peripheral trench. There are two ways of doing this: the discharge can either be caught in a metal basket, under water, or made to debouch on to the boat where it is sifted by hand as on a land dig. The latter is effected by attaching a length of pliant tubing to the top of the rigid tube. The pliant tube is held on the surface by a series of floats and its outlet fixed on board the boat. The disadvantage of this arrangement is that horizontal, surface extensions increase the chances of blockage. When matter leaves the vertical tube, it is carried along in a kind of foam. The power inherent in this emulsion is obviously less than in the flow of water in the other extremity, or the piston-like bubbles within the rigid tube. On the surface there is a tendency for particles to fall and adhere to the walls of the pipe, which eventually results in breakdowns and waste of time.

Unfortunately, readers are likely to be more familiar with accounts of mistakes made in the early days of underwater excavation than with the principles governing emulsion pumps. As stated above, the main difficulty is to raise matter to an *appreciable* height above the surface, a problem which seldom applies in wreck work where discharge takes place at the surface.

Initially at the Grand Congloué¹ the experiment of discharge in height was made and had to be abandoned. This early excavation caused great interest and resulted in publicity. The wreck being at the base of a cliff, a pliable extension was carried 5 metres above the surface so that it debouched on to the island itself. The wreck being at a depth of over 40 metres and the diameter of the tube 12cm., the power generated was considerable; moreover the machine was used indiscriminately, resulting not only in blockage but in breakage of the finds. In the light of subsequent experience, I have come to the conclusion that there is even a psychological danger in examining matter on the surface. Knowing that everything is going to be conscientiously sifted, divers become less scrupulous in their handling of the machine at the bottom. Small finds and organic matter are torn from their context, while waterlogged planks break under suction.

¹ J. Y. Cousteau, *National Geographic Magazine*, January 1954.

Fall-out

When the air-lift debouches into the water above the diver, it is logical to suppose that matter will sink back and cloud the working area, but this rarely occurs. Mud being light is held in suspension and forms a cloud on the surface. Slow-falling sand is carried away by an almost imperceptible current, while solid bodies such as shells are washed clean, so that they do not affect visibility when they land. More serious is the cloud of mud raised by any movement on the bottom itself, for this remains there in suspension. It can be cleared by holding the air-lift 1 foot above the ground so that it sucks up the cloud and draws in clear water. In conditions of absolute calm, it is conceivable

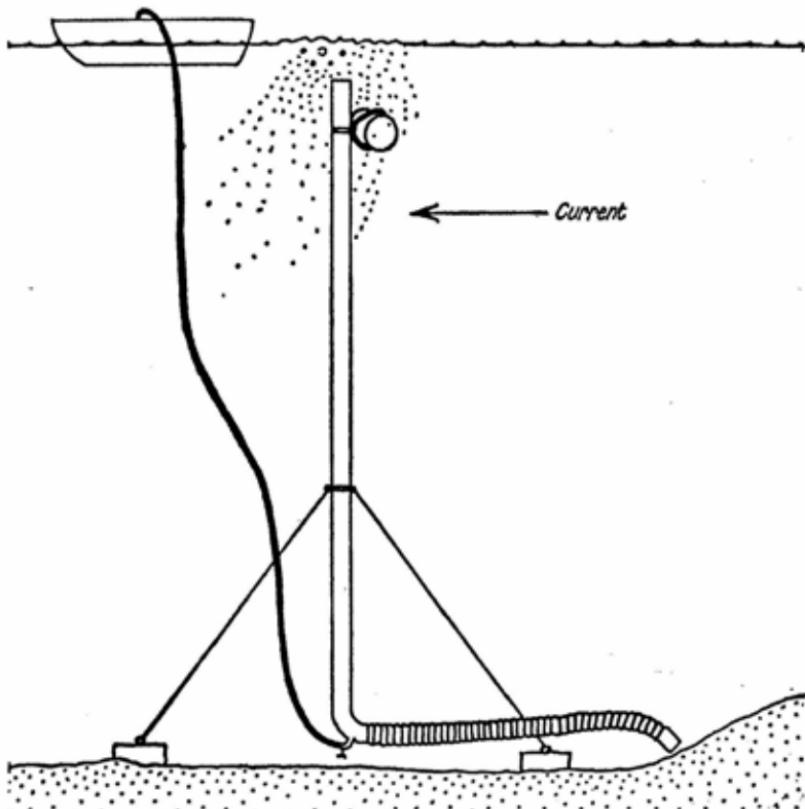


Fig. 7. Air-lift with a pliable extension at the bottom to avoid clouding caused by fall-out.

that discharge from above might form a cloud on the bottom; in this case I would suggest a longer extension of pliable tubing from the base of the rigid tube, keeping the input of air at the base of the vertical tube. The diver is then out of range of vertical fall-out while the danger of blockage inherent in horizontal extensions will be minimized, since, at the bottom, matter is carried along the tube in a strong current of water, before starting its ascent in piston-like bubbles.

An Adaptation for Shallow Water

A flexible extension from the base of the rigid tube, could be adapted, in certain cases, for use in shallow water. Such excavation involves entirely different problems, but it may sometimes be necessary to use an air-lift in 3 metres, or less of water; if the bottom slopes steeply it is possible to do this. The rigid tubes are moored in depth while the mouth at the end of a flexible extension, is used higher up. Air being injected at the base of the rigid tube, the column of emulsion is higher than the depth of water above the mouth. I have not had occasion to try this solution,

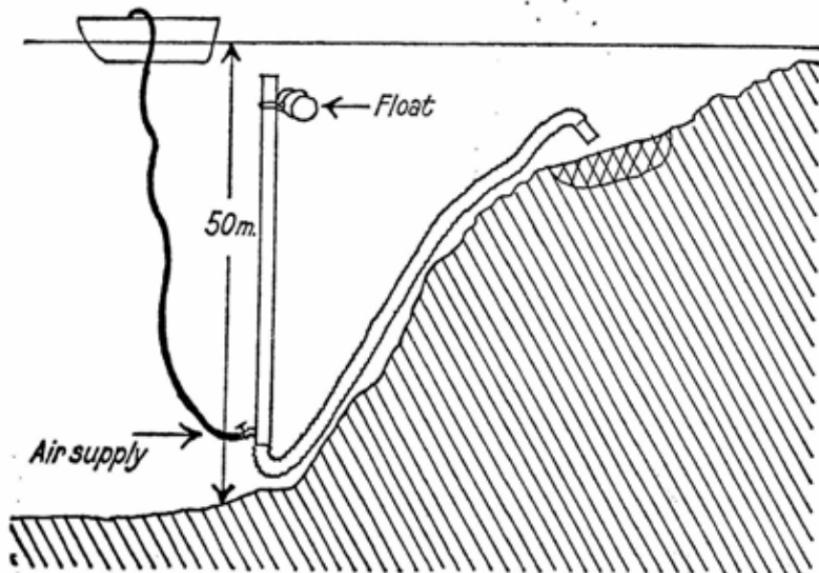


Fig. 8. A suggested method of rigging an air-lift so as to increase its power when work has to be done in shallow water.

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but it would have the additional advantage of giving greater mobility at the mouth and avoiding re-moorings. The degree of blockage such an arrangement would entail, remains to be seen.

Handling

Divers should add extra weight to their belts when handling air-lifts. Working either on their knees, or in a crouched position they learn by experience to face into the current so as to have clear water before them. Near the wreck area the mouth is held a few centimetres from the bottom, so that divers can see what they are lifting; when trenching, suction will be stronger if the mouth is in contact with the sand. The machine reacts to resistance because the intake of water is decreased while air is proportionally augmented; the emulsion becomes lighter and the suction increases. Air-lifts swallow anything: gravel, sand or loose mud at a rate difficult to imagine. Only certain compact forms of mud defeat them.

A Method of Lifting

Standard lifting devices need no adaptation for archaeological purposes and are too well known to warrant discussion. It is, however, worth mentioning a type of plastic balloon which is attached to an object and filled with compressed air under water. These balloons are sold on the commercial market; there are different sizes which can lift from 100 kilos to 1 ton. Pear-shaped, they have an opening at the narrow base, to which is affixed a series of straps for tying them to objects. Compressed air is introduced into the opening whence it automatically escapes, when expanding in the course of ascent. There is also a tap on top of the balloon allowing a diver to regulate buoyancy or deflate; this control can only be applied when the balloon is static. Heavy weight being nullified, an object can be raised by hand and its lower surface examined. It can then be set down again or brought to the surface as desired.

The appropriate size is determined by estimating the weight of the object to be lifted and calculating the equivalent cubic capacity of the balloon. A balloon starts its ascent half empty if

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it is too big, expanding air fills the entire space before being forced out; the speed of ascent being cumulative, the balloon gathers momentum and will jump out of the water, deflate and resink, with its load. Should it be necessary to use too large a balloon, disaster can be avoided by attaching a guide-rope by which a diver on the bottom can regulate the speed of ascent.

Lifting-Baskets

The most useful type of basket consists of a cubic iron framework, covered on five sides by coarse wire mesh. Two loops of rope, tied to the corners, act as handles and are attached to the cable from the boom or crane above. Delicate objects inside ordinary, reed baskets can be piled into these metal containers. Very fragile finds, or organic matter from the ship itself, have to be protected from water movement, especially on the surface. They must be put into rigid metal or plastic containers which can be closed, thus immobilizing the water around the object. There are occasions when ordinary plastic bags come in useful, for instance, for separating small labelled finds, before they are piled into reed baskets.

Tools

Most small tools work under water as on land, others are better if adapted to the denser element. A spade will always dig, but it loses some efficiency under water where sand is light and some flies off. The solution is to make a deeper and more closed spade, like a coal shovel, with edges to protect the contents. Instruments such as hammers, depending on rapid movement, lose power when speed is reduced, so it is better to have them slightly heavier than for the same job on land. Hammers also benefit from streamlining: long, narrow heads and handles which are oval in section offer less resistance. Divers must never forget that, since density is one of water's primary characteristics, water itself can be put to use. A hand-made current dusts as gently as a sable brush, it can also be made to move kilos of sand, or dig a hole around a buried object. Moreover, a diver using water power learns to dig sand or mud while at the same

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time, by a single movement, maintaining visibility by keeping a current of clear water in front of his mask. Such is the stock-in-trade of professionals, apprenticed to their craft.

EQUIPMENT FOR PROSPECTION

Mechanical Propulsion

Machines driven by electronic motors in watertight containers are available on the commercial market; they carry the diver more quickly than he could swim and, of course, without fatigue, at an average speed of 2 knots. The snag is usually that they cannot be navigated with sufficient precision to explore a uniform bottom, without landmarks. In contrary conditions: at the limit of rocks or Poseidon grass, they can be very useful when searching for a well-defined object. It should also be kept in mind that when these expensive machines have adequate navigational instruments, their complicated use distracts a diver's attention from the remains which, in any case, are difficult to see.

Sledges for Towing or a Weighted Line

Trailers towed behind a boat are also sold in shops; they are so designed as to allow the diver to regulate his depth and maintain visibility of the bottom. The simplest is a small board with a loop of rope fixed to its extremities and tied, in the centre, to the tow-line. A couple of handles, also at either end of the plank, suffice to steer it up or down. More complicated models have ailerons and bodywork to protect their riders from the impact of water. For systematic search, we have come to the conclusion that it is better to tow a diver on a heavily weighted rope (30 to 50 kgs.), than to use either of these machines. He hangs on to the line and soon learns, in relation to the specific job in hand, how long it should be and how heavy the weight. Towing speed must not exceed 2½ knots and, within this limit, the appropriate rate depends on the clarity of the water and the size and nature of the object for which search is made.

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The boat which does the towing must follow a predetermined course, or a series of parallel courses, within an area marked by buoys. Distance between her courses, as she sails back and forth, depends on visibility at the bottom and will be determined after a preliminary dive; overlap between the lines which have been investigated is subject to the ship's navigational accuracy. Lastly, from the diver's point of view, any mechanical propulsion which immobilizes him in a current of water is chilling and he should take the precaution of wearing a particularly warm suit.

Marker Buoys

There are two ways of marking objects found during prospection. For provisional use, the diver carries small markers hooked on to his belt. Made of rigid, cellular plastic, they are shaped like a reel with a length of nylon wound round and a lead weight attached to the extremity; the lead is tucked into the hole in the middle of the reel so that the whole thing is easy to handle under water. Once dropped, the lead sinks and the nylon unwinds automatically. Larger buoys, of standard design, are kept on the boat for long-term marking and for such purposes as defining the area to be surveyed.

Supersonic Sounding and Asdic

Supersonic sounders show, on paper, relief within a narrow strip of bottom directly below a ship. What appears to be a section on the paper is, in fact, the record of all the echoes within the radius of the beam projected vertically from the surface. There are self-contained models of echo-sounders which can be used on small boats. Asdic, based on the same principles, sweeps the bottom in all directions and is therefore more suited to our requirements, but relief has to be pronounced to register at all, and the instruments which are both costly and complex to work, have to be built into the ship.

In calm water and on a comparatively flat bottom, a wreck tumulus $1\frac{1}{2}$ metres high would give an echo on either instrument. Supersonic sounders record surface swell and this may be

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confused on the reading with the relief of the bottom. The beam from an echo-sounder, covering as it does such a narrow strip of bottom, poses depressing navigational problems while, in practice, the wider sweep of Asdic only locates objects on those exceptional, clean and flat areas of bottom. Accidental ground produces a multiplicity of echoes each of which must be checked by a dive, adding up to a Herculean task.

A portable instrument, no larger than a camera, which is a compromise between Asdic and supersonic sounders has recently been developed in America. The diver sweeps it across the bottom until it whistles, then follows the direction producing the echo. The note varies according to his distance from the object; again the instrument is only useful on an even, flat bottom.

Value of a Specialized Echo-Sounder

Specialized echo-sounders are coming into use on oceanographic ships for the study of marine sediments and sub-bottom. The type of echo-sounders usually used for depth indication do not indicate sub-bottom because their frequency is too high. Using a frequency well below 2,000 cycles per second the waves penetrate the bottom and are partially reflected by successive layers.¹ The reader who assumes the universal applicability of instruments now being developed may be surprised by the limitations of function indicated here, but as we have seen, ancient wrecks in no way resemble recent sinkings and many of these instruments were originally designed to detect submarines in time of war, or for oceanographic purposes like charting submarine hills and valleys. Military experiment is uneconomic compared to commercial expenditure, let alone an excavation budget; new devices are constantly being developed, but they are not necessarily suitable or available for our requirements. Even in routine salvage, if an aeroplane is lost at over 50 metres, it is often prefer-

¹ Brackett Hersey, Harold Edgerton, Samuel Raymond, Gary Hayward. *Sonar Use in Oceanography*. Fall Instrument-Automation Conference and Exhibit. New York City, New York, 26th to 30th September 1960.

Portable Sonar for Frogmen, I. R. Colldeweih, El. Wally and R. D. Lee. Electronics, 29th December 1961, McGraw-Hill Publication.

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able to drag the bottom, rather than attempt to locate the wreck, among so many accidental disturbances, by means of echo-soundings.

Television and Telecommunication

Television was first used, and with success, in 1957 on the submarine site at the Grand Congloué. The clear, luminous images it gives are of great help to non-diving and even to diving archaeologists, since the latter are not always on the bottom. However, there are two main drawbacks: first, the high cost of equipment, and secondly, the fact that to get a clear, comprehensible picture, the camera must be handled by a diver with some knowledge of film-making, in other words, a cameraman. A stationary camera, set up on the site, loses most of its utility, while a television team would almost double the personnel required on any one excavation. Assuming this luxury is feasible, television in addition to visual aid, allows archaeologists to give orders over a submarine loud-speaker of adequate range, either built into the camera case or in a separate container.

This brings us to telecommunications in general. Equipment being perfected, communication with the surface is, from a mechanical point of view, a practical proposition; it has been suggested that conversations could replace the written statements taken from divers as they surface. For psychological reasons, I would not recommend the experiment. To control five gardeners from an indoor telephone would be difficult and when the workmen are under water, wellnigh impossible. In order to speak, a diver has to wear a mask covering his entire face and then, he cannot make a statement and breathe at the same time, as he has to remove his mouthpiece. In the case of a competent, but inarticulate craftsman, the procedure would waste precious working time, while other divers might become garrulous.

Conditions of Work

Despite improved equipment, conditions of work under water remain abnormal. Cold, for instance, is virtually eliminated, at

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least for short dives, by the new neoprene suits, but nitrogen narcosis remains. Water pressure in itself limits the function of the brain; this phenomenon is well known, but has not as yet been explained. The experimental Diving Unit of the American Navy recently demonstrated that even at 30 metres, the function of the higher nerve centres starts to decrease. Symptoms intensify with depth: divers act mechanically, by routine and are incapable of interpreting unforeseen events. They accomplish their set tasks, but are occasionally subject to disconcerting lapses of memory. Only after years of practice can man recover, under water, some portion of his normal intelligence. Père Poidebard realized the implications of the dulled mind when he worked on the ports of Tyre and Sidon, and took signed and witnessed statements from divers as they surfaced.¹

Working time at the bottom is limited by risk of accidents and fatigue caused by diving. Accidents are avoided through strict adherence to decompression tables. Experience also shows that in the circumstances peculiar to archaeological sites, where diving continues uninterrupted for months on end, it is necessary to adopt a rhythm of work which precludes cumulative fatigue. This means keeping well within the accepted limits; as a rough indication I would suggest:

at 25 metres: morning 40 minutes, evening 30 minutes
at 40 metres: morning 20 minutes, evening 15 minutes
at 50 metres: morning 12 minutes, evening 8 minutes

For the same reason, stops of a few minutes should be made even when they are not necessary for safety, and the stops given on the tables should be prolonged. At least once a week there should be a break from diving.

As a result every archaeological task is carried out by successive teams of divers and there is no guarantee that each team will pursue the same line of conduct, even if material conditions are constant and there is, for instance, no variation in visibility. If an archaeologist can dive at all, he will still be unable to be on the bottom the whole time; he is obviously handicapped and his

¹ A. Poidebard, *Tyr*. Librairie Orientale Paul Geuthner. Paris, 1939.

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only remedy is a clear and honest appreciation of the limitations involved in the conditions of work.

It is also essential that the person in charge should be able to judge the individual capacities of his divers and allot tasks accordingly. Then again, if some crisis, in the form of delicate organic matter, should turn up after the archaeologist had surfaced, he should send for a Polaroid photo or even suspend work until he can see for himself.

Lastly, I should mention some instruments which I consider indispensable in the sort of methodical excavation which, it is to be hoped, will be undertaken in the not too distant future.

'Polaroid' Camera

On underwater excavations, there is a need for immediate photographic information. A non-diving archaeologist, or even a diver who has surfaced after his allotted time and cannot go down again, may wish to make a quick decision about some new discovery, while the draftsman, whose time is limited, is constantly in need of *aide-mémoires*. In order to fill this gap, for the 1960 excavation in Turkey, I conceived the idea of adapting a 'Polaroid' camera, which instantly produces a positive, for use underwater. Unfortunately, both case and camera were lost before they could be used in practice on the wreck but the trials were promising. Since then, a similar camera, but with a wider angled lens, more suitable for underwater work (which takes a film fast enough to give every satisfaction) has been developed.

Core-Sampler

A core-sampler is a tube with a cutting-edge at one end. It is driven into the ground, either by its own momentum (when dropped over the side of a boat), by an explosive charge, or by some form of power generated by mechanical means.

The tube cuts a cylinder, or core, from the bottom and this is raised within it. Where there is sand (mixed with pottery) the tube must cut by vibratory or rotatory action. This action will have to be generated by a built-in mechanism, powered hydraulically, by electricity or by compressed air.

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The tube itself should be three or four metres long with an inner diameter of thirty-five to forty millimetres.

The power is generated at the surface and relayed by electric wire, water or air-hose. When powered by compressed air, it is possible to make the unit self-contained by incorporating an air-tank, such as is used by divers.¹

Water Jet

This is a fireman's hose of the type in current use. It is extremely effective in moving sand and debris, and can even be regulated for delicate work. The displaced matter does not travel far: once it is swept aside by the hose it has to be removed by means of an air-lift. Various motor-pumps suitable for driving fire-hoses are sold on the commercial market. A powerful water jet has a strong back kick and must, therefore, be anchored on the site. It should be noted that a useful type of jet with a reverse action steadyng device is made by the firm of Galeazzi (La Spezzia, Italy).

Draftsman's Grid

It is beyond my competence to discuss the special problems of underwater archaeological recording. I should however mention a frame which I designed to facilitate the detailed recording of objects in a three-dimensional relationship. Unfortunately I was not able to test the machine on a wreck. It consists of a square frame, each side measuring five metres, made of tubular metal which is levelled and stood on metal spikes. A graduated metal bar slides across the two sides which are also graduated. Another vertical rule is attached to this transverse bar. The rule has both a vertical and a horizontal movement so that when it is placed above an object to be plotted, three readings will suffice to give the object's position in space.

When the area it covers has been plotted, the instrument is pivoted, by 90°, on one of its legs. It is reset on the remaining leg and on two new ones at the far side. The two original legs which

¹ Sverdrup, Johnson, Fleming: *The Ocean*. New York, 1949. Kudunov E.I. 1957: *Vibratory piston core-sampler*. Trudy Inst. Okean 25, 143-52.

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have been left standing, serve to relate the first to the second position of the frame and so on, on each successive move. Two air levels ensure that the frame is horizontal. The entire grid can be taken to pieces.

Cone of Clear Water

This instrument is invaluable for making detailed record photographs in muddy water. It is a transparent, truncated pyramid whose top facet is at a slightly wider angle than the lens of the camera. Its height and width must be sufficient to cover a reasonable area of bottom. Preferably, the top and bottom facets should be made of glass and the sides of light, transparent, unbreakable plastic. The cone is filled with clear water at the surface, then closed, carried down and placed above the subject. Once in place and the camera adjusted to three-quarters the height of the cone, good photos can be taken even when there is no visibility. It can also be used by a draftsman.

IV

Prospection

SUBMARINE archaeology and the contribution it can make to our knowledge of the past is by no means confined to wrecks. However, the techniques applicable to shallow water sites can be developed by archaeologists or even amateur divers, so that I shall stress only those aspects of the subject that depend on professional experience of diving. It would be unrealistic to propose that all wrecks should be excavated, since hundreds are already known in the Mediterranean and free divers discover new ones every year. As matters stand, these sites are pillaged for profit or subjected to methodless amateur experiment. The urgent need is that they should be classified as ancient monuments and so benefit from some sort of legal protection. In the circumstances there might appear little need to prospect for new sites, thus inciting further destruction; furthermore, until collaboration between professionals has resulted in the development of accepted excavation techniques, archaeologists may consider it safer to let matters stand. However, a time may come when it is both desirable and safe to prospect; in any case, the charting of wrecks, as distinct from their excavation, would produce information different in kind, relating to trade and navigation.

Sources of Information: Fishermen and Divers

Before undertaking systematic search of shoals, capes, coasts and lastly, flat portions of the sea-bed, all existing sites known to

fishermen and divers should be listed and examined. Fishermen are surprisingly familiar with the bottom of the sea. In shallow water (and surface visibility extends to 20 metres in most parts of the Mediterranean), they look through a 'calfat', or a bucket with a glass bottom, then fish according to what they have seen. In deeper water they put down nets or trawl and often draw up sherds and bits of wood with the catch. In 1935 a trawlerman working off La Ciôtat, found the concreted mass of Roman copper coins now in the Boreli Museum at Marseille. In 1877 a fisherman from Sanary brought up the bronze ram of a war galley, decorated with a Medusa Head; he sent it to a foundry where it was melted down.¹

Coral and sponge divers frequently notice antique remains. Both fishermen and divers hand on their stories from one generation to the next and so traditions accumulate. It is not always easy to win the confidence of these men and still harder to elicit precise statements, but the effort is worth while. They seldom know the use of marine charts and call reefs and capes by names that differ from the map; the only solution is to take the informant on board and hope that, on the spot, he will be able to pinpoint a site. When objects are found in nets, fishermen know only the area or line of trawl, from which they came. Experience teaches the prospector what margin of error to expect; he fixes marker buoys round the zone, then tows a diver back and forth across it on the end of a weighted line.

Sea Routes: the Zones to Investigate

Shoals, capes and offshore islands associated with the sea routes of antiquity will reward methodical investigation. Geological structure, proximity to ancient harbours, archaeological and documentary evidence, combined with some knowledge of winds and navigation will, taken together, indicate promising areas. Wrecks are found on sand, adjoining the base of dangerous rocks. Rocky slopes themselves, whether coastal or offshore, constitute another type of site, producing evidence of sea lanes in the form of jetsam and lost anchors (see Chap. I, p. 3).

¹ Emmanuel Davin, *Monographie de l'Archipel des Embiers*, 1941.

At the base of steep cliffs, divers should examine the line of rock-fall and contiguous sand; the significant area will be about 40 metres wide (see Chap. I, p. 5). Under almost vertical cliffs the rock-fall is relatively narrow, so a single diver can explore it. When the slope is gentler, there is a proportionate increase in the width of rock-fall and consequently, in the significant area, this can be covered by three divers swimming abreast along the shore; they stop and mark anything which looks unnatural on the bottom. Divers cannot be towed over this kind of bottom; on irregular ground they need to preserve their mobility in three dimensions. If the area is great, propulsive machines driven by electric motors may be required, but their use is limited (see Chap. III, p. 43). Even on land, it is impossible to look for tomb sites from a jeep.

Round offshore islands and shoals, the wreck bearing-zone is more widespread. Having struck a rock, a ship does not necessarily sink immediately; even if she is leaking she will be pushed by wind and current and if under sail, can continue for some distance. Nevertheless, chances of finding a wreck do, on the whole, diminish the farther one goes from dangerous rocks; in each case the prospection area will have to be limited by common sense and judgment. Lastly, it should be remembered that this type of wreck is likely to be in the line of the dominant wind or current.

What Wrecks Look Like

Prospectors must learn to recognize subtle variations from natural, geological structure. Growths and sediment camouflage sites more effectively than on land. The slightest abnormal protuberance on a sandy bottom, a sherd or an unnaturally shaped stone may indicate a buried wreck. These signs can only be interpreted by an eye long adapted to submarine conditions. Certain ancient wrecks are marked by no more than a rock with a strange shape in the midst of many other similar formations. Concretions can deform a single amphora, or cover the entire surface of a tumulus vaguely resembling the shape of a ship. When a diver breaks this crust he will be amazed to find under-

neath stacked, intact amphorae embedded like crystals in a geode. As cannons in later times, amphorae are the most precious indications of antique wrecks; this ubiquitous container of oil, wine, or even the crew's provisions was found on every ship. Wood from the top of a wreck is devoured by marine life, iron disappears within a covering of stone, only the amphora is eternal; it remains stable in time and even today, escapes the camouflage of sediment. I say 'today', because we do still come across classical wrecks, though these are on the point of being covered with sand. Their degree of burial does, of course, also depend on geological conditions and depth. There are on record a number of Byzantine ships where the top layer of amphorae are still loose, unconcreted and stacked, while on the same part of the sea-bed, earlier amphora carriers are almost invisible. Only by accumulating comparative evidence can we hope to arrive at a classification of relative states of preservation which, in turn, will suggest modifications to excavation technique.

Dangers of Ill-Considered Prospection

Moorings where debris have accumulated in the course of centuries are subject to sedimentation; objects become buried, others show and some appear to have been recently dropped; these latter often denote further buried remains. It is believed that the sea-bed is governed exclusively by natural laws, human intervention being forgotten, but boats have continued to moor since earliest times and their anchors sometimes pull pottery out of the sand. Remains are also deranged by nets dropped on top them, then dragged to the surface loosening objects as they go. Human interference disturbs sedimentation accidentally deranging finds of different periods, despite the natural stratification of the ground. This may explain sites, where only two broken amphora necks mark a buried wreck. Even octopus are to some extent responsible for disturbing sherds; they usually dig their homes in the bottom, surrounding them with solid objects such as the pebbles, sherds and shells they uncover, using them to embellish and stabilize the sand round their hole. I even

suspect these creatures of carrying their building materials from surrounding areas.

To the average diver, archaeological prospection consists in lifting antiquities and noting their position. It is hard to situate a wreck when this is far from land, or on a flat bottom off a uniform coastline and I very much doubt whether, in most cases, it is possible to chart the odd amphora neck with any degree of accuracy. It is easier to define zones and pinpoint finds within them. Moreover, most divers do not realize how much is buried under the sand, and destroy important archaeological sites by removing their last remaining surface marks. Interpretation of the plans they make, since these are based on surface finds, are often meaningless. Even if every object is accurately charted, leaving an adequate record for future archaeologists, we cannot suppose that many would return to examine an area, charted ten years earlier, for the sole reason that two amphora necks had been noted in a given position. Flair counts in prospection, and future archaeologists, with experience of submarine sites will, when confronted by certain remains, be in a position to formulate an interpretation, but once the evidence is removed, the trail is lost for ever. In coastal waters the number of ancient sites is limited; thanks to the constant levellings of erosion and degradations caused by the ever-increasing hosts of free divers, it is possible to envisage a not too distant future when no indications of trade routes will survive. We must hope that the study of offshore anchorages, analogous to certain aspects of land work, will be tackled by archaeologists equipped with appropriate instruments for sounding and taking sample sections of bottom for the analysis of strata, before these sites disappear.

A Corpus of Information: Conclusion

As long ago as 1955, at the First International Congress of Underwater Archaeology at Cannes, it was proposed that wreck sites should be recorded on a chart. At the Second Congress, in 1958 at Albenga, the creation of a permanent committee for charting in the western Mediterranean, under the auspices of the International Institute of Ligurian Studies was mooted.

Each wreck would provide certain information: the date of the ship, its provenance and stops, while the total number of wrecks charted would indicate trade routes and the relative importance of traffic at different periods. At present no general conclusions are possible as interest has been concentrated on amphora carriers and therefore to the possible contents of these jars. Even if we consider a one-way trade in amphora carriers, it is reasonable to suppose that an equivalent tonnage of perishable goods was carried on the return journey.¹ Then there is the isolated jetsam so common in the Mediterranean; though individual finds have no absolute significance they do mark the passage of a ship. The antique cargoes salvaged up to now show that, like modern sailors, the ancients carried on board ship a variety of objects from different parts and a single amphora from Rhodes may well have been dropped from a Roman boat.

The kind of offshore anchorage used for occasional trafficking with a nearby town would, on examination of the strata of the sea-bed, provide evidence complementary to wreck excavation. In the vicinity of a town it would be logical to expect the same sherds under water as on land, but interesting to go farther and discover the particular kind of pottery imported by sea. The other type of provisional anchorage, used when the wind was contrary, is marked by anchors and their stocks. At present these are difficult to identify, but once they are classified and type-series made, the significance of the site itself will emerge. Meanwhile the very existence of these places permits certain hypotheses regarding sea lanes and methods of navigation.

I am aware that these suggestions are somewhat beyond my province, belonging as they do to a no-man's-land between current archaeological practice and a possible future field of research. Since the invention of free diving twenty years ago, quantities of marine finds have reached museums where, unless they are works of art or interesting examples of pottery, they are relegated to cellars. Numerous anchors, lead winches, parts

¹ M. F. Benoit, *L'Economie du Littoral de la Narbonnaise de L'Epoque Antique. Rivista di Studi Liguri*, Nos. 1-2, 1958, Vol. XXV, Inst. International di Studi Liguri Bordighera.

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of rigging and ship's plumbing await study, and those who found them, guidance. The situation is difficult, for whereas other branches of science, such as geology and biology are making provision for the training of personnel in underwater research, no such facilities exist for archaeologists. Further, geological research is not threatened by the unbridled enthusiasm of amateurs, whereas archaeological remains are exhaustible. The techniques involved in excavation are no more difficult than in any other branch of submarine activity; the only danger is that if the nature and limitations of underwater work are not appreciated, unnecessary destruction will ensue.

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Deep-Water Recording

by Honor Frost

The Limitations

The limitations inherent in deep-water recording are: lack of horizon, distorted vision and the dulling of the mind in depth. These may not be felt by the experienced diver who has learned to compensate, but their side-effects always remain serious for the draftsman.

Lack of Horizon

Divers move in three dimensions and there is no horizon under water; in bad visibility they can become so disorientated that they do not know whether they are going up or down and are taught to pause and observe the direction of bubbles from the valve, then follow them to the surface. All surveying techniques and instruments: plane table, alidade and theodolite are based on a known horizontal level. Under water, there is not only a lack of horizon, but there are no instruments which will give depth measurements accurate to at least 1 metre. New instruments are being developed but they are in an experimental stage and do not solve the problem of measurements over a long distance. Existing depth gauges become progressively more inaccurate after about 25 metres.

Distorted Vision

Divers learn to compensate for distortion, but certain side-effects remain serious for the draftsman. Masks enlarge by a quarter, while restricting the angle of vision. The diver is like a horse wearing blinkers, and loses that standard of comparison given by a normal field of vision.

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His three-dimensional mobility makes it natural for him to swim at a convenient distance from, and with his body always parallel to the bottom. This combined with the slow motion of swimming and the enlargement of objects on the narrow strip of ground below, makes him like a very small fish in a big world. In addition, lack of cast shadow in depth renders relief imperceptible; it is possible to see that a rock sticks out of the ground, but harder to realize that the ground itself is on a slope whereas on land a variety of sensory messages from leg muscles and eyes all indicate uneven ground, if the underwater draftsman's task is to measure two points 12 metres apart, on uneven ground, and then do detailed drawings along that line, he will hammer in key points and stretch a tape between them, then proceed to measure individual objects and their inter-relationship. At this point, the lack of a known horizontal is fused with distorted vision, for there will be a discrepancy between the overall measurement and the sum of the details, which could be corrected on paper if (a) the overall measurement had been horizontal, and (b) if the depth of the small declivities were known.

Effect of Depth on the Mind

Lastly, there is the effect of depth on the mind. This is the easiest limitation to overcome. Once the draftsman is conscious of the degree to which he is personally affected, he compensates by planning his dive in advance. The mind functions automatically but is incapable of posing questions, so the draftsman lists his objectives and crosses off each as it is accomplished.

POSSIBLE SOLUTIONS

A Measuring Machine

M. Dumas has described, with no less feeling than a draftsman, the difficulty of recording free-standing surface concretions of Baroque shape. Happily these do not occur on every wreck and where they do, they are confined to the surface layer, so that there is no point in enlarging on his conclusions or attempting to deal with the other abnormalities of wreck formation.

Let us consider a 'normal' wreck where three layers of amphorae are held together and buried in sand, above the flattened remains of a hull. For such sites, Dumas has designed a machine for recording in three dimensions, throughout successive phases of excavation. It consists of

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a square metal grid with graduated sides. This is stood on adjustable, metal legs over one section of the site and the sides set horizontally by means of a spirit level. A bar, also graduated and, of course, automatically horizontal, slides across the grid at right angles to two sides and to this is attached a graduated rod with vertical motion, serving as a plumb-line. This rod can be moved back and forth across the bar as well as up and down. When its tip is placed above an object, three readings suffice to give the position in space. After one square has been

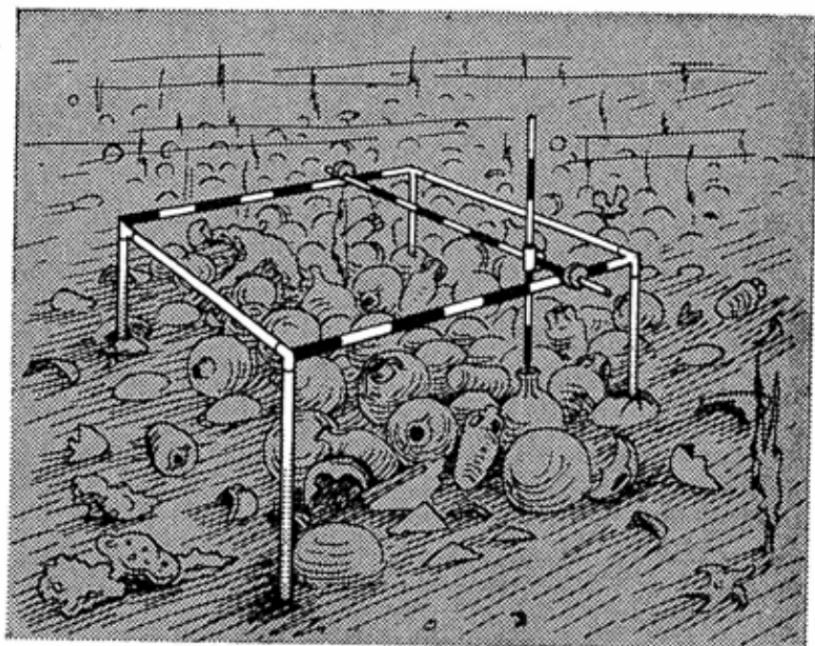


Fig. 9. The measuring machine.

recorded in this way, the grid is swivelled on one leg; three legs are left standing (for the next level of drawing), one is re-used and two more are added on the far side. The grid is again set by spirit level. In this way the entire area is divided into squares and each can be drawn accurately and in depth as layers of cargo are removed in the course of excavation.

On paper, this conception appears a complete answer to the problem. Unfortunately, in practice, the variety of site and the requirements of excavation as distinct from making plans, often make it impossible to use a standard machine. Each would have to be constructed to meet the

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specific requirements of individual wreck formations, just as an air-lift would. The instrument could not, for instance, be used on a very uneven bottom, or on a site where a ship has settled into a fissure of rock echoing its own lines. Further, small grids would get in the way, pinning divers under their sides and requiring frequent resettings with a consequent loss of accuracy, while large grids with sides 5 metres long would have to be worked by two assistants, unless the draftsman were to keep swimming from one point to another resetting the bars, before returning to his drawing.

It seems to me that an alternative solution, based on conventions which accord with working conditions, should be sought, instead of attempting, by mechanical means, to impose a non-existent horizon. For this, the nature of a wreck formation and its particular requirements, in terms of recording, must be reassessed.

Land Analogy: Architectural Survey and Tomb Recording

On land there is a distinction between surveying architectural remains and recording the contents of a tomb; the subjects being different in kind, they cannot be described by exactly the same type of visual convention. In order to reconstruct a building, the foundations must be surveyed, since a horizontal, ground plan will explain the size and nature of the structure. It is more important to record the accurate alignment of a course of masonry, than to draw each individual block. On the other hand, in a large tomb chamber we are confronted by a number of skeletons, each with jewellery and weapons, and surrounded by tables and dishes bearing funeral meats. All these objects are different and have originally been placed deliberately, in a certain functional relationship; it is therefore necessary to draw and describe each one separately. Distances are, of course, measured, but it would be easier to reconstruct the whole from even a free hand, perspective drawing, than from an accurate vertical plan where each pot was shown upright as a series of concentric circles.

Tombs and Wrecks Similar in Kind

When choosing the appropriate visual convention for recording a certain kind of event, we see that tombs and wrecks present similar problems. At the same time we must remember that a wreck is a self-contained mechanism, like a car, which has landed by accident on the bottom of the sea. If a car crashed over a precipice, disintegrated and became a heap of metal parts, we should observe that the remains bore

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an accidental relationship to their surroundings and a functional relationship to each other. Knowing that cars existed, our primary aim would be to understand the nature of the crash, then the juxtaposition of the fallen parts, so that they could be reconstructed. Neither the car nor a wreck is imposed on nature by man's will, therefore, unlike the foundations of a house, their relationship to the ground, though significant, is of secondary importance.

In a tomb, the beads which once encircled a lady's neck are now fallen among vertebrae, but we can still see the relationship. Similarly on a wreck, the lead rings for furling the sails may now lie scattered amongst the surface layers of cargo. Though calculable, the law of gravity is more complex under water. In neither case would it be possible to reconstruct relationships in the same way a surveyor dots in a missing stone on a plan; it is the juxtaposition of individual objects which is of paramount importance in tombs and wrecks.

The Variety of Visual Conventions

The vertical plan is one way of describing a certain type of event. There is no limit to the possible number of visual conventions; plans and sections, mathematical perspective and isometric projections all describe things in three dimensions, while Chinese paintings and Persian miniatures show that one object is behind another by putting the former higher up on the paper. Cézanne showed that recession could be described in terms of colour. Conventions are based on the nature of the information communicated and the limitations inherent in the medium used.

The Actual, as Against an Imaginary Horizontal Plane

With wrecks a collapsed mechanism has to be explained by the juxtaposition of its parts; the limitation imposed by circumstances on the draftsman is a complete lack of horizon, which rules out normal survey techniques. What he can do under water is to make completely accurate measured drawings of the objects in front of him, on the plane on which they lie. There is no satisfactory way of projecting an inclined plane back on to the horizontal under water. It is axiomatic that no operation should be undertaken in depth which can more easily be accomplished on the surface. The problem at the bottom of the sea is to draw what is in front of one and find some means of relating this accurate measured record to the objects which will appear below, when the top layer has been removed in excavation. If this can be done,

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there will be sufficient data to make it a simple matter, on land, to project the inclined plane on to the horizontal, if this is really necessary.

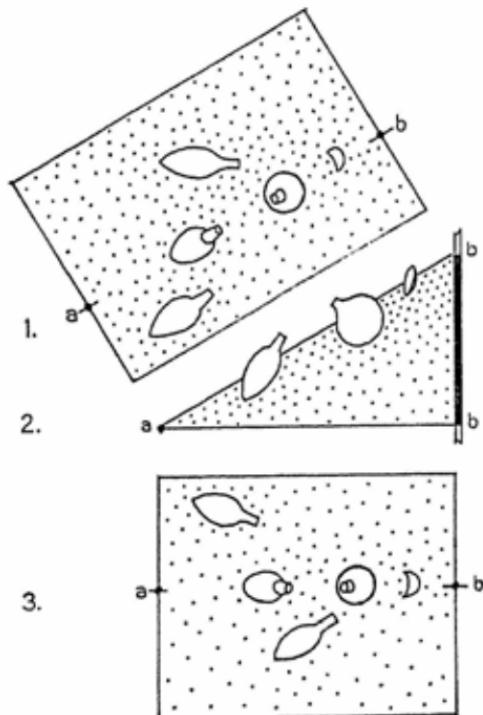


Fig. 10. (1) Underwater drawing of objects measured on the actual plane on which they lie, showing poles stuck into core-holes at a and b. (2) Section a-b with depth measured on core-pole b-b. (3) Projection of a-b on to a horizontal plane.

Key Measurements in Depth

I would suggest that one way of getting this data is a natural corollary of Dumas's method of excavating a wreck by coring. The significant area of wreck will have been raised above the surrounding bottom by means of a peripheral trench; cores will have been made across the axes and round the periphery. Metal rods, running right through the wreck, will have been stuck into the core holes. Let us assume that the tops of these rods which stick out of the tumulus are not more than 2 metres apart; if the distances are very great, a few more rods can be added. The draftsman's first task will be to go round with a surveyor's pole with a spirit level affixed, marking off the top of each rod at the

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same level. This will be his only direct concession to the non-existent horizontal. After that, he sets to work to make a measured drawing of an area of cargo bounded by three of the rods. The triangle can easily be defined by tying tapes between the three rods. The objects and the distance between them are measured, on the plane on which they lie, by means of a rule, callipers, proportional dividers, or any other instrument suitable to the size and nature of the finds. Their placing within the small area defined can be double checked by triangulation from any two of the three rods. Double checks are essential under water. The draftsman then establishes the slope of this triangle by making a mark on each rod, where it sticks into the ground. Naturally, if there is a protuberance or declivity within the area, it can be measured in a similar way in relation to the rods. At no point will the draftsman be required to make unnecessary underwater calculations, or be expected to project what he is drawing on to an imaginary plane. A mosaic of triangular scale drawings will result and be repeated at each successive level of excavation. When put together, the successive phase plans will be of slightly different sizes, according to the varying slopes

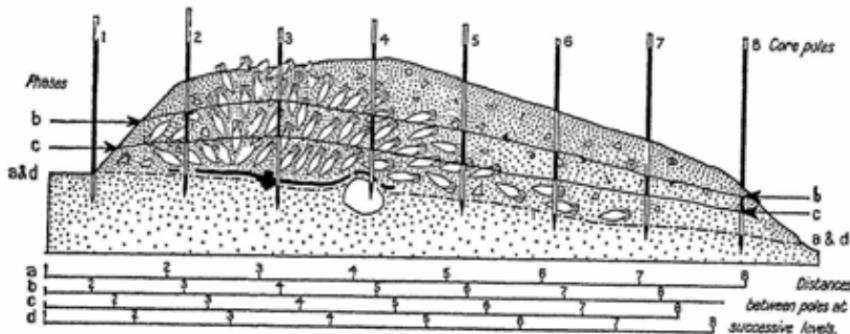


Fig. 11. Section of a wreck-tumulus (with peripheral trench) showing 8 poles which have been stuck into core-holes. A given horizontal has been marked, by means of a spirit level, on the protruding part of each pole and below it another mark has been made (a-a) where the pole enters the sand. When the first layer of finds have been removed the poles are again marked (b-b), and so on through layers c-c and d-d. Measured drawings will have been made of the objects on the actual planes on which they were found. The variations in these successive measurements are illustrated below on lines taken between the various levels recorded on the poles. The depths being known, all measured drawings can be related to each other and projected on to a horizontal plane as in Fig. 10.

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at different periods in the excavation, but the sectional, or depth measurements, will be recorded by the marks on the rods. To relate the two sets of data on land may be tiresome, but it is feasible and legitimate. On the surface it can be accomplished with a modicum of care and common sense.

Instruments

The only means of taking depth measurements, other than those described above, are: soundings by line from the surface and depth-gauge readings. Worn like a watch, the depth-gauge can conveniently be used over a large, even area, to establish the general slope, but it will never give detailed measurements. Depth-gauges are often numbered in metres from 1 to, say, 20—after that they are numbered in units of 5 metres. Drawings can be made on metal or plastic sheets with an ordinary lead pencil. Surveyor's poles, draper's rules and other measures used on land need no alteration; choice is governed only by the nature of the objects to be drawn. Lines or tapes for long measurements must be made of materials which do not stretch or shrink under water.

Photography

Excellent record photographs are made under water; it is only necessary here to mention aspects of the subject which affect the draftsman. It is assumed that, because a diver can get directly above a wreck, a photographic overlay is a substitute for drawn records. Unfortunately this is far from true; underwater photographs are in no way comparable to aerial surveys, owing to the impartiality of marine camouflage and lack of cast shadow which makes photographs of archaeological subjects difficult to interpret, even by divers. Further, the maximum distance from the bottom which will give a satisfactory overlay photograph is only 3 metres.¹ Naturally a successful photographic overlay of a site is useful and when compared, supplements the information on a drawn plan. It should be noted that Dimitri Rebikoff has suggested a method of making underwater stereoscopic photographs giving the necessary relief.²

¹ Gianni Roghi. Note Tecniche sul Rilevamento e lo Scavo della Nave Romana di Spargi. *Bollettino e Atti*, 1958-9. Centro Italiano Ricercatori Subacquei.

² Dimitri Rebikoff, *Photographie Sous-Marine*, p. 48.

Bulletin Officiel du Club Alpin Sous-Marine, No. 8, 1956, Cannes.

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There is, however, a type of *aide mémoire* photograph, usually unsuitable for permanent record, which can be very useful to the draftsman. When important relationships, such as pieces of wood, have to be drawn on the bottom within a limited time, incidental surroundings such as rocks can be photographed and entered on to the plan on the surface. Draftsmen can either take their own *aide mémoires*, or have them done by a special assistant photographer. When this method is used, it follows that both date and time of each photograph has to be recorded, as sand is so mobile that a scene can change in the twinkling of an eye. What looked like a rock in one dive may be covered by sand and appear a small stone in the next and hinder the interpretation of records when they are compared after a lapse of time. Needless to say, this ephemeral type of photograph must either be taken by polaroid camera or, if not, it must be developed and printed for use the same day. All underwater notes must be copied on land immediately or confusion will result.

Bibliography

U.S. Navy Diving Manual. Navy Department, Washington 25 D.C., 1959.

Royal Naval Diving Manual. Underwater Warfare Division, Naval Staff, Admiralty, S.W.1.

La Plongée. Marine Nationale, Arthaud, Paris.

'*Variations en Mer de la teneur en oxygène dissous au proche voisinage des sédiments.*' Jean Brouardel et Louis Fage. Institut Océanographique Monaco.

THE AIRLIFT

Carl Immanuel Löscher, *Erfindung eines aerostatischen Kunstgezeuges.* Leipzig, 1797.

G. Schmetzler, *Ueber eine neue Methode der Wasserhebung aus tiefen, vertikalen Brunnen.* Deutsche Bauzeitung, 1876.

Werner Siemens, *Eine neue Methode Wasser zu heben.* Dinglers Polytechnisches Journal, 1885.

Werner Siemens, *Entwässerung einer Braunkohlengrube.* Verhandlungen des Vereins zur Förderung des Gewerbefleisses, 1885.

Gerlach, *Mitteilung über die erste Druckluftheberpumpe von Löscher.* Z.d.V.D.I., 1885.

E. Josse, *Versuche mit Mammutpumpen* Mitteilungen aus den Maschinen-Laboratorium der Kgl. Technischen Hochschule zu Berlin, Verlag R. Oldenbourg, München, 1899.

E. Josse, *Druckluftwasserheber enthaltend.* Z.d.V.D.I., 1898.

König, *Pressluftpumpen für Wasserförderung.* Hydrotekt, 1902-3.

Wittrock, *Verwendung von Pressluft zum Heben von Flüssigkeiten.* Z.d.V.D.I., 1904.

Darapsky und Schubert, *Die Wirkungsweise der Pressluftpumpen.* Z.d.V.D.I., 1906.

BIBLIOGRAPHY

L. Darapsky, *Zur Theorie der Pressluftpumpe*. Dinglers Polytechnisches Journal, 1913.

L. Darapsky, *Die Berechnung der Pressluftpumpen*. Dinglers Polytechnisches Journal, 1908.

Folke-Rasmussen, *Die Wirkungsweise der Pressluftpumpen*. Dinglers Politechnisches Journal, 1908.

W. Karbe, *Die Arbeitweise und Berechnung der Mammotpumpen*. Journal für Gasbeleuchtung, 1912.

H. Lorenz, *Die Arbeitsweise und Berechnung der Druckluft-Flüssigkeitsheber*. Z.d.V.D.I., 1909.

Erfahrungen mit Mammotpumpen beim Schachtabteufen. Z.d.V.D.I., 1904.

K. Hoefer, *Untersuchungen über die Strömungsvorgänge im Steigrohr eines Druckluftwasserhebers*. Dissertation, Berlin, 1912.

K. Hoefer, *Mitteilungen über Forschungsarbeiten*.

K. Hoefer, Z.d.V.D.I., 1913.

A. Perenyi, *Rationelle Konstruktion und Wirkungsweise des Druckluft-Wasserhebers für Tiefbrunnen*. G. W. Kreidels Verlag, Wiesbaden, 1908.

A. Perenyi, *Ueber die Anwendungsweise der Druckluft zum Wasserheben*. Journal für Gasbeleuchtung, 1911.

B. Schneider, *Mammotpumpen zur Hebung solehaltiger Mineralwasser in Salsomaggiore*. Dinglers Polytechnisches Journal, 1913.

Th. Steen, *Mammotpumpen zur Untertunnelung der Spree*. Zentralblatt der Bauverwaltung, 1911.

Th. Steen, *Druckluftwasserheber unter besonderer Berücksichtigung der Mammotpumpe*. Z.d.V.D.I., 1901.

Th. Steen, *Erfahrungen mit Mammotpumpen in Bergwerksbetriebe*. Glückauf, 1921.

Th. Steen, *Mammot-Rührwerke*. Chemiker-Zeitung, 1926.

Th. Steen, *Die Mammotpumpe in der Kali-Industrie*. Ztschrft. Kali.

Dabrowsky, *Druckluft-Wasserheber*. Zeitschrift des Berg- und Hüttenmännischen Vereines Kattowitz, 1936.

R. E. Browne und H. C. Behr, *Dr. Pole's air-lift pump*. Transactions of the technical Society of the Pacific Coast, 1890, February.

Edward A. Rix, *Pumping by Compressed Air*. Journal of the Association of Engineering Societies, 1900.

A. H. Gibson, *Hydraulics and its Applications*. New York, 1908.

A. H. Gibson, *On the motion of long air bubbles in a vertical tube*. The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, 1913.

BIBLIOGRAPHY

Edmund M. Ivens, *Pumping by compressed air*. New York, 1920.

A. W. Purchas, *Some notes on air-lift pumping*. Engineering, November 1917.

A. W. Purchas, *Water-supply for California oilfields*. Proceedings of the Institution of Civil Engineers, Volume CXCIII.

Randall, Browne and Behr, *The air-lift pump*. Engineering News, 1893.

Hoorweg, *Upvoer van vloeistoffen uit groote diepte*. Delft, 1921.

Hoorweg, *De Luchtlift*. De Ingenieur, 1921.

E. G. Harris, *The Theory of the Air-Lift Pump*. Journal of the Franklin Institute, 1895.

E. G. Harris, *Air-Lift Pump, Theory and Computations*. Compressed Air, 1910.

Dr. J. S. Owens, *Experiments on air-lift pumping*. Engineering, 1921.

John Oliphant, *Air-Lift Pumping*. Canadian Engineer, 1919.

Air-Lift Pumps. The Engineer, 1903.

Hiscox, *Compressed Air*. London, 1905.

J. Davis and R. Weidner, *An investigation of the air-lift pump*. Bulletin 667 of the University of Wisconsin, 1924.

C. N. Ward and H. Kessler, *Experimental study of the air-lift pumps and applications of results to design*. Bulletin 1,265 of the University of Wisconsin, 1924.

Sullivan Machinery Company, Chicago, *The Sullivan air-lift pumping system, methods and apparatus*. Bulletin No. 71-G.

Sullivan Machinery Company, Chicago, *Sullivan air-lift for railway water supply*. Booklet No. 129.

Compressed Air Magazine, 1902.

M. L. Jannin, *Théorie de l'aspiration pneumatique des liquides*. Revue de Mécanique, 1909.

R. Masse, *Les Pompes*. Paris, 1903.

Theremin, *Recherche sur la figure et le mouvement d'une bulle d'air dans un liquide de densité constante*. Crelles Journal, 1830.

Frizell, *Experiments on the compression of air by direct action of water*. Journal of the Franklin Institute, 1880.

E. J. Gealy, *Air-lift pumping system quickly raises water from flooded anthracite mine*. Coal Age, 1925, Bd. II.

W. L. H. Schmid, *Over de Verking van de Luchtlift voor water*. Dissertation, Delft, 1930.

Kray, *Der Widerstand von Sandkörnern und Kugeln bei der Bewegung im Wasser*. Mitteilungen der Versuchsanstalt für Wasserbau und Schiffbau, 1921.

BIBLIOGRAPHY

F. Münzinger, *Der Wasserumlauf in Steilrohrkesseln*. Z.d.V.D.I., 1920.

F. Münzinger, *Die Leistungssteigerung von Grossdampfkesseln*. Verlag Springer, Berlin.

Witz, *Wasserumlauf in Rohrkesseln*. Wärme, April 1924.

H. Kratz, *Die Betriebswasserversorgung der Laurahütte-Grube in Laurahütte*. Z.d.V.D.I., 1923.

Blasius, *Das Achnlichkeitgesetz bei Reibungsvorgängen in Flüssigkeiten*. Mitteilungen über Forschungsarbeiten.

Schneiders und Schwemmann, *Durchteufen fester Gobirgssechichten nach dem Versteinungsverfahren*. Glückauf, 1914.

E. Schmidt, *Der Wasserumlauf in Steilrohrkesseln*. Festschrift: Fünfundzwanzig Jahre Technische Hochschule, Danzig, 1929.

E. Schmidt, *Der Wasserumlauf in Steilrohrkesseln* (Auszug aus 64). Z.d.V.D.I., 1929.

St. Lüffler, *Das Zeitalter des Hochdruckdampfes*. Z.d.V.D.I., 1928.

Gleichmann, *Das Bonson-Verfahren zur Erzeugung hochgespannten Dampfes*. Z.d.V.D.I., 1928.

Abendroth, *Dampfkraftanlage mit Bensonkessel im Kraftwerk der Siemens-Schuckertwerke*. Z.d.V.D.I., 1927.

E. Josse, *Hochdruckdampferzeugung durch Atmoskessel*. Z.d.V.D.I., 1925. 'Hütte'. *Das Ingenieurs Taschenbuch*.

Regeln für die Durchflussmessung mit genormten Düsen und Blenden. V.D.I.-Verlag, Berlin, 1930.

L. Schiller, *Untersuchungen über laminare und turbulente Strömung*. Mitteilungen über Forschungsarbeiten.

Ruppel und Jordan, *Die Durchfluszzahlen von Normblenden mit und ohne Störung des Zuflusses*. Forschung auf dem Gebiete des Ingenieurwesens, 1931.

Stodola, *Dampf- und Gasturbinen*. 5. Auflage, Berlin, 1922. Verlag J. Springer.

F. Pickert, *Gesichtspunkte für den Gebrauch von Druckluftwasserhebern im Bergbau*. Glückauf, 1932.

F. Pickert, *Das Wesen der Druckluftwasserheber und ihre Verwendung im Bergbau*. Kohle und Erz, 1932.

W. Roelen, *Verwendung von Mammutpumpen beim Schachteufen*. Der Bergbau, 1932.

H. Behringer, *Die Flüssigkeitsförderung nach dem Prinzip der Mammutpumpe*. Dissertation, Karlsruhe, 1930.

Cleve, *Modellversuche über den Wasserumlauf in Steilrohrkesseln*. VDI-Forschungshefte, 1929.

BIBLIOGRAPHY

Green, *Efficiency of the air-lift as a solution pump*. Engineering and Mining Journal, 1909.

Miyagi, *Theory of the air-lift pump with special reference to the slip of air bubbles in the water*. Technology reports of the Tohoku University, Japan, 1924.

Lely, *Mathematische Berechnung der Druckluft-Flüssigkeitsheber*. De Ingenieur Den Haag, 1925.

Vers Luys, *De werking van de gaslift*. De Ingenieur Den Haag, 1928.

Purchas, *Die Lufthebepumpe*. Chemical and Metallurgical Engineering, 1920.

Purchas, *Das pumpen von Säuren mit Pressluft*. Chemical and Metallurgical Engineering, 1920.

Shaw, *Principles of the air and gas lift*. The Oil and Gas Journal, 1927.

Bennet and Slater, *Some new aspects of the gas lift*. American Institution of Mining Engineers, 1927.

Bowing, *New developments in hydraulic pneumatic engineering*. Journal of the Royal Society of Arts. London, 1929.

S. A. Zulbin, *Vorgänge bei der Verleinerung von Luftblasen*. Werft Rhelderei und Hafen, 1930.

Stepanoff, *Thermodynamic of the air-lift*. Transaction of the American Society of Mechanical Engineers, 1929.

Nesselmann, *Über Messungen an kleinen Mammutpumpen*. Wiss. Veröffentl. a.d. Siemenskonzern, 1937. Bd. 6.

René, Champlly, *L'air comprimé ou raréfié*. Chez Dunod, 1929, Chap. Pompage par émulsion.

Picker, F., *Wirkungsgrad und Berechnungsgrundlagen von Druckluftwasserhebern*. Sisserstation Technische Hochschule, Berlin, 1931.

Pickert, F., *The theory of the air-lift pump*. Engineering 11 juillet, 1932.

Payne, *Air-lift pumping*. Soc. Engrs J. 1949. Vol. 40, No. 3.

Jean Lefèvre, *Relevage par émulseur*. Technique del'ingénieur A. 991.

L. Darapsky, *Die Verwendung der Pressluft zur Wasserförderung*. Berg- und Hüttenmänische Zeitung, 1903.

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